Proposal for Research ESU 64-42

RESEARCH IN INTELLIGENT AUTOMATA (Phase I)

Prepared for:

OFFICE OF THE DIRECTOR
DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D.C.

STANFORD RESEARCH INSTITUTE

MENLO PARK, CALIFORNIA

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Office of the Director
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FOREWORD

For several years the staff of the Engineering Sciences Division of Stanford Research Institute has been interested in the concept of Intelligent Automata. Some months ago, it was concluded that recent advances in the fields of adaptive pattern recognition, learning systems, and information processing made the initiation of such a program appropriate. A study group was formed to develop the guidelines for a coordinated program of research. This proposal is the result of the combined efforts of the members of this study group.

The study group was composed of engineers and scientists representing all of the laboratories of the Division. The members of the group are listed below.

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SUMMARY

Stanford Research Institute proposes a program that will ultimately lead to the development of machines that will perform tasks that are presently considered to require human intelligence.

Significant but uncoordinated research studies applicable to this field are being carried out in a number of laboratories. We propose--in a balanced program of experimental, theoretical, and exploratory research--to coordinate the efforts of a large group of specialists within and outside the Institute, directed towards the orderly development of theory, technique, and hardware.

Several key problem areas have been identified and will serve as the basis of our initial work. These include, among others, research in adaptive pattern recognition, in learning systems, and in adaptive autonomous generation of sub-goals in a multilevel goal-seeking system. In addition to the necessary exploration of these areas by analyses and simulation, it is intended to develop a machine facility to permit operation with models that will embody desired concepts, but will avoid superfluous engineering design. By thus concurrently implementing theoretical results, major practical problems will not be overlooked, costs of real solutions may be assessed, and the operating models can also serve a major purpose in the generation, clarification, and simplification of complex ideas.

The machine facility will comprise adaptive learning machines, digital computers, and large memory systems, which, with suitable interface equipment, will permit the rapid assembly of the information-processing portion of an intelligent automaton. The automaton proper may take many forms, passive as well as active. It is planned to demonstrate one or more versions of an active mobile machine organized as a goal-seeking automaton, learning to perform tasks in a complex and changing environment--tasks that would normally be considered to require intelligence.

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I INTRODUCTION

A. Intelligent Automata

This proposal deals with the conception and development of techniques and machines that will aid or supplant man in performing certain tasks that are usually considered to require "intelligence." Since no universally acceptable definition of intelligence* is available, let us define, like Turing,** what we mean by an intelligent automaton, operationally. An intelligent automaton is a machine that can perform acceptably tasks that normally require more or less continuous human control or intervention for acceptable performance.

We shall attempt to divide these tasks into three groups. In Group I are those tasks that are now being performed or will presently be performed by machines. In Group III are those tasks that appear too difficult for machines of the near future. Between these two extremes is a group of tasks, Group II, whose performance by future machines appears

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*Two quotations will illustrate the difficulty in defining "intelligence":

Minsky's view is that intelligence "is more of an aesthetic question, or one of a sense of dignity, than a technical matter ... a complex of performances which we happen to respect but do not understand." "Steps Toward Artificial Intelligence," M. Minsky, Proc. IRE 49, pp. 8-30 (January 1961).

Pollard offers as "a cynical definition of Artificial Intelligence [that] it is a property of a system or machine which appears to give the capability of decision-making in a manner which is not readily apparent to an audience; however, when this property is explained in a logical manner it is deemed not to be intelligence because it is explainable." From a preface by B. W. Pollard, presented at Artificial Intelligence Sessions, Winter General Meeting IEEE, New York (27 January 1963).

**Turing's operational definition of a "thinking" machine was that it was one which could answer questions posed by a human questioner sufficiently well to deceive him into believing it was human. From "Can a Machine Think?" in The World of Mathematics, J. R. Newman (Ed.), Simon & Schuster, New York, N.Y., Vol. 4, pp. 2099-2123; 1956.

now to present problems of intermediate complexity and difficulty. The solutions to some of the problems in Group II will require substantial progress, but many of the problems can be solved by applications of techniques being developed now in the fields of adaptive pattern recognition, heuristic programming, and learning systems. The solution of the problems posed by the Group II tasks will be the basis for the proposed research program.

The grouping of the tasks is as follows:

Group I: Tasks Whose Solutions are Presently Attainable

The performance by machine of the tasks in this group has either been demonstrated or can be demonstrated with techniques and equipment now developed. Several of the tasks require machine performance which--although presently accepted as commonplace--would have been considered evidence of intelligent behavior not very long ago. In other cases, the performance is attained by methods which are cumbersome and perhaps uneconomic, and widespread use awaits the development of new techniques and specialized equipment. Examples of Group I tasks are:

(1) Automatic control of drone aircraft, including take-off and landing, flying on a pre-set course, and target acquisition.

(2) Complete environmental control for humans in space vehicles or stations, including integrated control of temperature, humidity, oxygen and carbon dioxide, air circulation, and other functions necessary for life and comfort.

(3) The rough (and barely acceptable) translation by machine of scientific Russian into scientific English.

(4) Machine-controlled factory manufacturing process, such as the cracking of hydrocarbons in an oil refinery.

(5) Machines that can play checkers and automatically improve their game strategy--by experiencing many games--until they can play in championship style.

(6) Machine proof of mathematical theorems in plane geometry and logic, starting with a list of axioms.

Group II: Tasks of Intermediate Difficulty

The performance of tasks in this group presently requires either continuous human control or considerable human intervention. These tasks would be classified by most people as tasks requiring "intelligence"; in some cases they may be too difficult to cope with for most humans without machine aid; in all cases it is evident that something more "intelligent" than the most intelligent primate, other than man, is required. Techniques and machines devised to do these tasks could be applied to simplify greatly the methods of doing Group I jobs, as well as serve as the foundation for attempting the far more difficult tasks in Group III. Some examples of Group II tasks are:

(1) Machine recognition of voiced commands with a constrained "language of discourse." For example, one could program a digital computer or alter an existing program by spoken commands; the selection of words (and sentences) would be restricted to the small vocabulary representing a formal programming language (e.g., Algol).

(2) Machine control of city-wide traffic. This is an example of a control problem with so many complexly-related variables that ordinary analytic methods cannot be applied, even with large-scale digital computers. The situation is further complicated by the need to cope with sudden unforeseen traffic tie-ups caused by accidents, fires, the weather or other changes in the traffic environment, or slowly changing conditions due to evolving traffic patterns.

(3) Control of unmanned mobile vehicles with complex operational capabilities. These may take many specialized forms--e.g., for submarine patrol vessels for home water protection; land robots for exploration of the moon, or sea robots for exploration of the ocean depths; tank-like patrol vehicles primarily designed as mobile information-gathering posts in a hostile and changing environment.

(4) A chess-playing machine that, given complete rules and principles of the game, could learn to play championship chess. This task is typical of those in which the number of possible alternative courses of action is so huge that exhaustive search and evaluation of each course is clearly impossible, thus requiring a strategy starting with the ultimate goal and establishing tree-like structures of sub-goals, with a consequent enormous reduction in the search and evaluation process.

Group III: Tasks for Later Generation Intelligent Automata

Tasks in this group require attributes of human intelligence such as creativity, induction, intuition, and concept formation--qualities that are poorly understood and consequently difficult to emulate. Relatively few humans possess such qualities to the degree required to perform these difficult tasks; the impact of these qualities is such that machine augmentation of these abilities of man could have a revolutionary effect on all of society. It is suggested that attainment of these capabilities be considered as long-term goals for later-generation automata with this "higher order of intelligence." It seems probable that work leading to development of automata to perform Group II tasks will serve as a foundation for automata for the Group III tasks; on this assumption, prime emphasis in this program will be placed on the Group II tasks. However, it is possible that entirely different and new

concepts and principles will be required and early exploration is considered advisable. Examples of Group III tasks are:

(1) Machine decision-making on a level of middle and executive management in competitive situations, of economic, political, or military origin. This group is composed primarily of complex game-like situations.

(2) Machine translation from the literary works of one language into another, maintaining the original quality. Primarily this group requires methods of abstraction and concept formation.

(3) Machine composition of music, writing of poetry, conception of physical theories. This group emphasizes creative and inductive qualities.

We should note here that one attribute of all of the Group III tasks is "quality." Even now some tasks similar to those listed above can be performed, but their performance is generally of a low quality. Since quality is an aesthetic matter difficult to measure by numeric indices, one can readily appreciate the difficulties and possible controversies that will attend the eventual implementation of Group III tasks.

Implementation of the tasks in Groups I, II, and III provides a spectrum of problems. One end of this spectrum is rooted in engineering practice; the other is beyond our current imagination. It is our contention that techniques now being developed can soon be applied to achieve machine performance of Group II tasks. The purpose of this proposal is to outline the first phase of a program whose end goal would be to see tasks similar to those of Group II performed by intelligent automata.

The point of view to be adopted in this first phase is as follows:

(1) Key research problems will be identified whose solution would permit the realization of operationally useful intelligent automata.

(2) Simulated and actual models will be developed which are stripped of most of the difficult engineering design that would exist in an operationally useful system, but which expose the key research problems to critical examination.

(3) As solutions to key problems are obtained, functions will be added to the modeled systems until there exists sufficient complexity to permit implementation of useful applications.

A principal reason for this approach is the awareness that as the initially identified research problems are attacked, other crucial areas will appear. As our understanding increases, so will our ability to formulate more precisely the key questions, and to know when enough of the important ones have been asked and answered. Initially this process should go on unencumbered by the difficult, but purely developmental, engineering necessary for an operationally useful system.

B. Long Range Objectives of Intelligent Automata Program

The industrial revolution changed the whole fabric of human society by placing under the productive control of man powerful sources of physical energy. About the middle of the Twentieth Century, a second phase of this same industrial revolution began. This phase is placing under the productive control of man powerful sources of intellectual energy based on electronic machinery. It is a strong conjecture that the continuing development of intelligent automata superposed on existing machine capabilities will provide the basis for a rapid increase in the progress of this new revolution. It is impossible to predict the courses that these developments may lead to, but it is wise to set long-range goals to guide these developments.

Our proposed program will point toward the following long-range goals:

(1) To develop intelligent automata that can exceed man's abilities in performing specialized tasks.

(2) To develop intelligent automata that can substitute for man in performing tasks in environments hostile or unpleasant to him.

(3) To develop intelligent automata that can aid man in performing a broad range of tasks more rapidly, more accurately, and more efficiently than man alone can accomplish.

So that our long-range goals are not too distant, we shall assume that these tasks to be performed by intelligent automata are all tasks whose level of difficulty would place them in Group II.

The achievement of each of these long-range objectives will confer its own special advantages. Some of these are listed below, grouped according to the objective spawning them.

<u>Characteristics of Automata that Exceed Man's Abilities</u>

(1) Memory approaching complete recall

(2) Handling of many simultaneous inputs (hundreds to thousands, rather than 5 to 10)

(3) Control of large numbers of outputs simultaneously

(4) High response speed

(5) Almost continuous operation

(6) Greater range of sensing--e.g., the whole electromagnetic spectrum, the whole sonic spectrum, specialized chemical, and physical property senses

(7) Increased range of specialized output equipment--e.g., wheels, valves, printed data, etc.

(8) Ability to make absolute as well as relative measurements.

Characteristics of Automata that Can Substitute for Man in Hostile or Unpleasant Environments

(1) Operation under extremes of temperature, nuclear radiation, or sound (noise)

(2) Operation in chemically or biologically poisonous or dangerous environments

(3) Execution of missions potentially dangerous to human life

(4) Operation in remote areas for long periods of time (such as in space, on the moon, in the deep sea) without need to supply needs other than energy sources.

Characteristics of Automata that Can Supplement Man

(1) Provide man with advanced aids for intellectual pursuits, including problem-solving, research, equipment design, operation of complex fabrication processes.

(2) Relieve humans of routine, semi-repetitive tasks that may require occasional human supervision and control.

(3) Linked together with humans in an integrated system possessing a greater speed of response, a larger information-handling capacity, and sensory abilities beyond those of man alone.

C. A Research Program for the Development of Intelligent Automata

It is proposed that a long-range research program be initiated with the following objective: to develop intelligent automata capable of performing tasks similar to those listed in Group II. It is impossible to state precisely how many years will be required to achieve this objective, but at least three major phases can be seen clearly at this time:

Phase I --Theoretical and experimental research in key problem areas, development of foundations for an analytical theory of intelligent machines, demonstration of intelligent behavior in special laboratory apparatus (3 years).

Phase II --Continued experimental and theoretical research on specific crucial problem areas pinpointed by Phase I; selection of large scale application(s); scaled simulations of these application(s) on special purpose equipment similar to that developed during Phase I.*

Phase III--Implementation of a prototype system.*

This proposal deals with Phase I only. In the following section we shall identify and discuss some key research problems that must be attacked during this first phase; then we shall be able to outline the objectives, the plan of attack, and the specific research tasks of Phase I.

D. Key Research Problem Areas

By initial study of the character of the tasks in Group II--the Group of intermediate difficulty--it has been possible to abstract three pertinent critical research problem areas. This list is by no means exhaustive, nor can one be certain at present that some crucial areas have not been omitted. If major problems are solved in the listed areas, however, not only would substantial progress have been made in implementing the desired intelligent automata, but the remaining problems, listed or not, will be exposed and defined, prime requisites for successful attack and solution.

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*At the present time it is impossible to estimate the amount of time required for Phases II and III. It may be possible that these Phases could be accelerated by parallel effort.

These key problem areas are the following:

(1) Adaptive Pattern Recognition of Events and Sequences of Events

(2) Adaptive, Autonomous Generation of Subgoals and Actions in Hierarchically Organized Structures

(3) Implementation by Hardware and Software.

In order to see how these problem areas bear on the development of intelligent automata, it will be necessary to examine each of these areas in detail.

1. <u>Adaptive Pattern Recognition of Events and Sequences of Events</u>

Information gathered by many sensors must be filtered, reduced, and classified by the intelligent automaton if it is to react usefully with the environment. This essential function, pattern recognition, when broadly interpreted, refers both to patterns arising from a single method of sensing, such as the visual recognition of spatial objects, as well as to the recognition of patterns that may be composed of signals arising from many sensors simultaneously. For example, if the task were hunting, visual, acoustic, and olfactory sensing information would have to be integrated to identify game under wide-ranging environmental conditions. An obvious parallel exists in the correlation of signals from many sensory modalities in antisubmarine warfare. Furthermore, much of the information of interest is in the form of time-varying signals, and thus our pattern-recognition system must introduce time into the multidimensional signal space. Depending on the problem, the size of the time interval associated with and defining each pattern must be chosen; this interval need not be fixed, being shorter when a great deal of pertinent change is occurring in the environment. Such a composite pattern covering prescribed intervals in a number of different modalities (e.g., a region in space, an interval in time, a band of radio frequencies, etc.) can be defined as a single event.

Pattern recognition of an even more general nature is required for time sequences of such events as defined above. This may involve a

higher order pattern recognizer whose inputs in a given time sequence are the outputs of the lower order pattern recognizer. For example, sequential recognition of each of the following events: light flash, loud noise, high atmospheric ozone, evidence of smoke and carbon dioxide, rise in temperature, etc., may provide the input data for the higher order recognition of the fact that lightning has struck and caused a forest fire. The recognition of such a composite event could set in motion the necessary instructions for obtaining further information, such as location, size, etc., so that efficient fire-fighting procedures could be initiated.

The most difficult and important of the problems in the areas of adaptive pattern recognition arise in connection with the word "adaptive." It is this adaptive feature that is a necessary part of the pattern recognizing capability of any machine we would call intelligent. By adaptive pattern recognition we mean that the rules that the machine uses to classify raw sensory information are evolved from the experience of the machine itself, rather than by prior, detailed analysis by the machine's designer. If part of this experience was controlled and organized by a human (or by another machine) we shall say that the machine has been <u>trained</u> to recognize patterns. The advantages of adaptation and training in pattern recognition are two-fold: first, adaptation allows the automaton to cope successfully with a changing environment, and second, training offers the possibility of evolving pattern recognition capability beyond that presently possible by conventional predesign techniques.

An adaptive pattern recognition machine of the type that would be useful in an intelligent automaton has been constructed at Stanford Research Institute. The machine, known as MINOS II, is described in a paper, entitled "A Large, Self-Contained Learning Machine," which accompanies this proposal as Exhibit A. MINOS II is now being successfully used in several problems involving prediction and pattern recognition.

Two highly important problems requiring considerable further work are those of preprocessing and selective attention.

The preprocessing problem is one of finding and developing methods to cope with the vast amount of sensory information usually available--to filter, sample, or to abstract essential features, so that ultimately recognition can be accomplished with a reasonable amount of equipment.

The problem of selective attention stems from the requirement that the pattern recognition subsystem be able to concentrate on or attend to, selectively, that portion of the total received information that is most important at a particular time, the criteria for relative importance having been established by some logical process elsewhere in the automaton.

2. Adaptive, Autonomous Generation of Sub-Goals and Actions

Ultimately, we desire our intelligent automata to be able to achieve one or more specified goals. This operation is to take place under environmental conditions sufficiently complex or unpredictable that a human "boss" is not able to predetermine (and therefore program) the exact sequence of events that will occur, or the proper actions to be taken from start to finish. As previously stated, the number of possible courses of action to achieve desired goals is so huge that methods involving exhaustive search are out of the question. However, if it is possible to break down the problem into a tree-like structure of goals, sub-goals, and sub-sub-goals, etc., the search procedure can be greatly reduced.

To the extent that the human designer can anticipate the possible experiences of the automaton in solving a particular task, he can "design in" the most appropriate sub-goals, sub-sub-goals, etc., for each goal likely to be specified. This "predesign" of the automaton is analogous to inherited instincts in humans and animals. Certainly nothing is to be gained in forcing the automaton to learn those sequences of sub-goals known *a priori* to be useful.

The major research problems, however, fall in the area of adaptive and autonomous generation of sub-goals. Here the automaton must

learn by experience those useful sequences of sub-goals that its designer was unable to anticipate. Here also, controlled and organized experiences can be used to train the machine. It is envisioned that the successful performance of most of the Group II tasks will require automata having a combination of a sophisticated hierarchy of built-in sub-goal sequences and the capacity for autonomous sub-goal generation.

Let us illuminate some of these problems of constructing and using sub-goal sequences by considering an example having a number of different levels of complexity.

At the simplest level, let us assume a sub-goal that does not vary, is known beforehand, and can thus be programmed. For example, suppose we had an unmanned mobile vehicle whose goal was a specified destination, and to reach it from any given starting point, a field of various obstacles had to be traversed, one of which was a stream that could be forded at a <u>known</u> single place. As a sub-goal, the machine could be programmed to seek a least costly path through the obstacles to the known fording position, first, and then to proceed to find another acceptable path to the final destination.

Suppose the exact position of the fording place was not known, although it was known that a fording position was probably available. The above sub-goal of seeking least costly paths to and from a fording position remains, but we now have added a sub-sub-goal, which is: to locate a suitable fording place. Then the sub-goal routine for finding least costly pathways is repeated. A programmed routine for finding a sufficiently shallow passageway would either have to be developed as a separate item or learned by the automaton itself.

Suppose it was known that there was a stream that must be forded quite frequently, but the fording position varied occasionally with time in some unpredictable manner. The above goal, sub-goal, and sub-sub-goal procedures, if followed, would lead to solutions, but search procedures for finding least costly pathways would have to be implemented each time. It might be more feasible, once and for all, to make a <u>model</u> of the terrain, with each obstacle labelled as to type and

position. Thus when the fording position was ascertained by the sub-sub-goal routine, the least costly pathway would be determined by operations on the mathematical model, rather than by an exploration procedure physically enacted by the vehicle. These pathways would be used until they were found to fail--i.e., until the fording position changed. The routine for establishing the model, in an appropriate memory, would be a sub-sub-goal. One can proceed a further step if all obstacles can vary unpredictably as to type and position.

Finally, suppose that some types of obstacles are not known beforehand and therefore no breakdown of goals, sub-goals, etc., can be predetermined. Here methods must be developed that make use of whatever information is available or can be developed by experimental or logical means, tempered by past experience in similar situations. These procedures, loosely termed heuristic methods, are only partially developed at present, and represent major research problems, requiring intensive study and attack by a combination of analytical and empirical methods. Exhibit B, accompanying this proposal, outlines those developments in heuristic methods that seem pertinent to this program.

Summarizing, we have seen the need for structuring our research problem, making use of:

(1) Known information

(2) Information developed by experimental or exploratory routines

(3) Information developed by operation on a model, so that prediction can be made to determine the efficacy of hypotheses, and

(4) Information developed by heuristic methods.

3. Implementation by Hardware and Software

Once schemes have been proposed for a hierarchically organized automaton capable of recognizing complex patterns in a changing environment and capable of generating sequences of sub-goals and actions

appropriate to the achievement of an over-all goal, there remains the problem of economically implementing these schemes by actual equipment. Since we foresee that certain types of available equipment will be needed to implement any scheme for an intelligent automaton, we can anticipate the problem of integrating these equipments into an efficient coordinated system. These types of equipment include the following:

(1) Adaptive pattern recognition apparatus (sometimes termed learning machines), such as MINOS II

(2) Apparatus to perform logical operations, such as a digital computer

(3) Apparatus in which to store information, such as random-access storage and content-addressed, or associative storage.

A related area in which research problems can be seen is that of software. Suitable programs will have to be developed for loading the automaton with its initial instructions and for communicating with it during operation. These programs may involve the use of special programming languages (e.g., LISP, IPL-V).

Research in the key areas of adaptive pattern recognition and autonomous sub-goal generation, and the development of hardware and software necessary for economic implementations, has been started and is continuing at a number of different places. No single group, however, seems to have achieved or even proposed the broad scope that is being proposed here. The prior experience of Stanford Research Institute in these areas equips it uniquely to undertake a coordinated program of research on these problems necessary to the development of intelligent automata. The proposed research program--Phase I in the long-range development of intelligent automata--is such a coordinated effort. Its specific objectives are stated in the next section.

II PHASE I OBJECTIVES

Phase I is envisioned as a three-year program. Its specific objectives are:

(1) To pursue a coordinated effort of theoretical and experimental research aimed at the solution of the major problems in the key areas identified in the Introduction. These are:

   (a) Adaptive pattern recognition of events and sequences of events;

   (b) Adaptive, autonomous generation of subgoals and actions;

   (c) Implementation by hardware and software.

(2) To develop the theoretical foundations for analysis and synthesis of intelligent machines.

(3) To demonstrate adaptive, intelligent behavior in special laboratory apparatus. This demonstration should reflect the progress and still-remaining problems in the key research areas.

The remainder of this proposal will discuss the methods by which we propose to meet these objectives.

III PLAN OF ATTACK

To achieve the objectives of Phase I we propose a combined theoretical and empirical approach. A wealth of theoretical and experimental background in adaptive pattern recognition, learning systems, adaptive control, and digital logic can be brought to bear on the key problem areas.

A major amount of the analytical effort will be devoted to the solutions of problems of adaptive pattern recognition and goal-structuring by an automaton in complex and/or changing environments. Digital computer simulations will be employed to test and to develop further promising models suggested by the theoretical work. The analytical work will also be buttressed by continuing critical evaluations of contemporary developments as they occur in the fields of pattern recognition, heuristic programming, automata theory, and related fields.

We contend that the greatest rate of progress toward the objectives can be made now by supplementing theoretical (and simulation) studies with an empirical approach based on a special machine facility hitherto not assembled. This facility will consist of the necessary hardware and software to implement a hierarchically-organized, goal-seeking automaton capable of (1) interaction with a complex and indeterminate environment, and (2) behavior arrived at by an internal choice of subgoals and actions that are automatically adapted toward improving performance. The functions that we propose to implement within this automaton are described in Sec. IV of this proposal.

As visualized now, this facility would consist minimally of an integrated system of digital computer(s), adaptive pattern recognition machine(s), and various types of memory, including associative memory. Also required would be interface and input-output equipment, including sensors and adaptive controllers such that efficient communication could be effected between the whole complex and the environment, and internally between machine and machine. With these equipments, experimental

research could be conducted on major functions such as multimodal pattern recognition on several levels, including time sequences, modelling and prediction, logical combination and ordering of events, all controlled by a master stored program. An essential feature would be the ability for the complex to change its operation by processes of adaptation (or learning) when exposed to a varying environment. Major subsystems--e.g., the pattern recognition machine(s) and digital computer(s)--will share this ability to change or adapt. The information storage subsystem(s) shall consist of both long- and short-term memories, including content-addressed as well as the usual types of computer memories. A more detailed description of the proposed equipment for implementing this automaton is presented in Sec. V.

A major focus and source of direction for both the theoretical and the experimental research to be conducted during Phase I will be provided by the objective of demonstrating learned, intelligent behavior in the automaton to be assembled. We are proposing to conduct specific experiments for this purpose that will serve to exemplify the key research problems. The exact nature of the experiments will be determined during the early part of Phase I. Our opinion now is that the experiments will probably involve a small motorized vehicle, directed by the automaton, carrying out tasks that have been learned in a complex and changing environment. More details on sample experiments will be presented in Sec. IV.

IV FUNCTIONAL ASPECTS OF PROPOSED AUTOMATON AND SOME PROPOSED EXPERIMENTS

A. A Model for Research in Intelligent Automata

We have chosen a goal-seeking automaton as a focal point for our research in machine intelligence. This automaton can be viewed as a machine that uses abstracted sensory information derived from its external environment to generate a set of actions that lead to the attainment of the goal. The goal is provided the machine by the human experimenter. The generation of actions is guided by stored, abstracted experiences (memory), as well as by the logic of its own internal construction.

As a focal point for this program we wish to study and experiment with a simplified model of this process. The key elements of the model are:

(1) The external environment

(2) The sensory system

(3) Stored, abstracted experiences

(4) Logical power to produce actions to satisfy a goal

(5) The goal.

A heuristic that is of proven merit for the economical attainment of goals is the process of setting up sub-goals. In general, the goal structure might be many levels "deep" and some levels "wide" (many sub-goals having to be fulfilled simultaneously). In order to abstract from such a structure a model of sufficient complexity to illustrate the main ideas but simple enough to represent an appropriate beginning, let us first consider a simple machine of only two levels and only one chain of goals. Such a hypothetical machine is diagrammed in Fig. 1.

Let us call the goal provided by the human experimenter the <u>main goal</u>. The process of satisfying this goal is directed by a subsystem of

the automaton that we shall call the "cognitor." The cognitor, under the influence of the main goal, is charged with the responsibility of converting abstracted sensory information into a sequence of sub-goals.

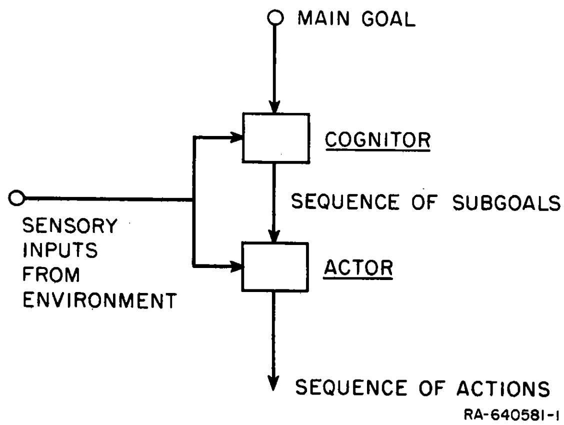

FIG. 1 TWO-LEVEL AUTOMATON

We assume, of course, that this conversion is conditioned by stored experiences. Another subsystem of the machine, called the "actor," is charged with the responsibility of converting abstracted sensory information into a sequence of actions directed toward the attainment of each of the sub-goals specified by the cognitor. The actions which are the output of the actor are commands to the response system of the automaton. They might be signals to turn on motors, print a line of type, flash lights, etc., depending upon the type of automaton.

The hierarchical structure just described finds applications in many diverse situations. Elaborations of this model have been used to describe social organizations, industrial corporations, computer programs, etc. Its embodiment in hardware has been used to control machinery of a wide variety of forms for the performance of a wide variety of complex tasks whose difficulty would place them in Group I. We seek to endow this proven hierarchical structure with two new attributes so that it can

be applied to the more complex tasks of Group II. These new attributes, themselves only recently beginning to be understood, are the following:

(1) Recognition of complex spatial and temporal patterns in the environment. This recognition is to be largely learned rather than "built-in."

(2) Autonomous determination of sub-goals and actions. In the past all the sub-goals were patiently "designed in" to meet anticipated experience. Here we want to allow the actual experiences of the machine itself to provide an additional means of sub-goal selection.

The early period of the proposed program will be devoted to the synthesis of methods by which we hope to endow the demonstration automaton with the capabilities of adaptive pattern recognition and autonomous sub-goal selection. Efforts directed toward refinement of these methods into more powerful techniques will be continued throughout the duration of the program. At present, we have some ideas which will serve as a point of departure for this research; these ideas will be outlined in this section of the proposal.

B. Basic Functions of the Cognitor and Actor

We may, to a first approximation, assume that the major functions performed by the cognitor and the actor are identical. Each, under the influence of a goal, converts abstracted sensory information into a sequence of sub-goals (or actions) in a way which is mediated by past experiences. Let us examine, in detail, a minimum set of functions that might be incorporated in one of these levels, say the actor.

The actor receives abstracted sensory information from the environment. The sensory information might, for example, consist of visual, acoustical, and tactile impressions. The abstraction is to be performed by learning machine pattern recognition equipment. That is, the information to be received by the actor will be processed into categories that experience and training indicate are meaningful.

Let this abstracted information at any particular time be denoted by an n-dimensional vector, $\vec{X}_t$, called the input vector. The components of $\vec{X}_t$ each represent certain learned meaningful qualities of the environment. For example, the i-th component may be a measure of the total sound energy between 1750 and 1800 cps; the j-th component may be a binary (1, 0) number which is equal to one if there is a large obstacle in the path of the automaton and equal to zero if the path is clear. $\vec{X}_t$ represents the sum total of information supplied to the actor from the external environment at time t. The important thing to note is that many of the abstractions used in reducing this information should be learned by the automaton itself rather than designed in ahead of time. This learned abstraction can be accomplished by adaptive pattern recognition equipment.

Central to the discussion of the operation of the actor (and the cognitor, also) is the notion of a "state." By a state, we mean a particular set of input vectors. If the automaton is a moving vehicle, some examples of states might be:

(a) rolling down an incline

(b) trapped in a pit

(c) touching a wall

etc.

The automaton could be in any of these states in a number of different ways. That is, the possible input vectors, $\vec{X}_t$, resulting from being in the state "rolling down an incline" might be many. For this reason we speak of a state as being a set of input vectors.

The notion of states is important in our discussion because we are going to use this notion in discussing goals. We shall assume that the sub-goal supplied to the actor by the cognitor is the directive to be in one of the possible states. The actor must then generate an appropriate sequence of actions to take it from whatever state it currently finds itself in to the desired state. When this has been accomplished, the cognitor supplies the actor with another state directive, etc.

Two problems are of special importance in the present formulation:

(1) The problem of learning which states are important ones as sub-goals toward achieving the goals that the human experimenter specifies.

(2) The problem of learning to recognize (by a process of pattern recognition) these important states from knowledge of $\vec{X}_t$.

It is to be anticipated that the problem of recognition of what state the automaton is presently in can be handled adequately by adaptive pattern recognition equipment. The problem of learning which states are likely to be important ones is more difficult and will demand much attention.

An additional problem of no less importance is the one of determining the sequence of sub-goals and actions necessary to take the automaton from the present state to the desired state. This determination should be done in a way that makes use of the past experiences of the automaton. Various suggestions have been advanced to solve this problem, and these will receive our critical attention during Phase I. One of these suggestions is treated in detail in the next section because it exemplifies some important features that will probably be present in any useful solution.

C. A Suggested Method of Implementing Autonomous Selection of Actions

We shall conclude our discussion of the functional aspects of the automaton by a suggestion for a partial solution to the problem of learning autonomous selection of actions directed toward a given sub-goal (state). To the extent that this suggestion is successful for determining action sequences it can also be used successfully to determine sequences of sub-goals. Figure 2 illustrates schematically the various states that past experience and training have indicated were important. The lines connecting the states indicate that at one (or various) time(s) in the past the automaton actually traversed between the states connected.

If the sub-goal is to be in state S_g and if the present state is S_t, the actor must decide what actions to take to achieve the sub-goal.

If the automaton had some experience in traversing between the various learned states, then the stored results of this experience can be used to generate an appropriate sequence of actions.

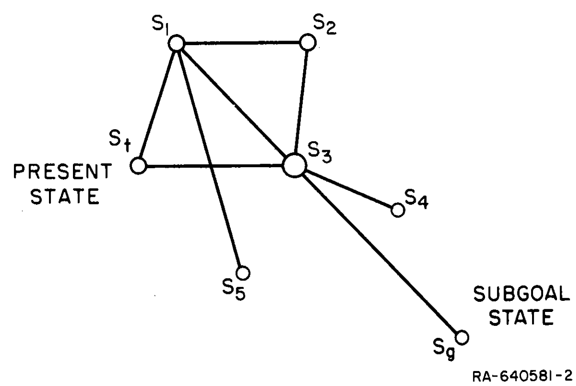

FIG. 2 STATE DIAGRAM SHOWING EXPERIENCED PATHWAYS

The results of experience can be stored in the automaton in a variety of ways. Sequences of actions that have proven to be always efficient in taking the automaton from one particular state to another can be stored in memory to be evoked whenever this transition is desired in the future. In this context, an associative or content-addressed memory would be useful. Experience of a less complete nature should also be used to direct the generation of action sequences. Such sequences of actions can be regarded as "inspired guesses" based on limited experience rather than the "table look-up" process used when more experience is available. We believe that the process of generating inspired guesses is fundamental to intelligent behavior. The following paragraphs contain one approach for implementing this process.

Suppose the automaton were in state S_t and it is desired to go to state S_g (the sub-goal). Suppose that there are just k actions available. If the actor could predict what state each of these actions would put it in, and if it could compare or evaluate these consequent states

against the sub-goal (S_g), then it would have a reasonable method of selecting the action. It should select that action that will leave it in the best place relative to the sub-goal.

The following is a method of predicting the consequences of each of the various k actions. These predictions can be made by adaptive pattern recognition equipment. Suppose we have k of these devices, called predictors. Each predictor has as its input the input vector at time t, $\vec{X}_t$, and as its output a predicted input vector at one unit of time later, $\vec{X}_{t+1}$. For each i = 1, ..., k, the i-th predictor gives the best prediction of $\vec{X}_{t+1}$ based on taking action a_i. These predictions are trained, automatically, as the automaton experiences its environment. The block diagram of Fig. 3 shows this function.

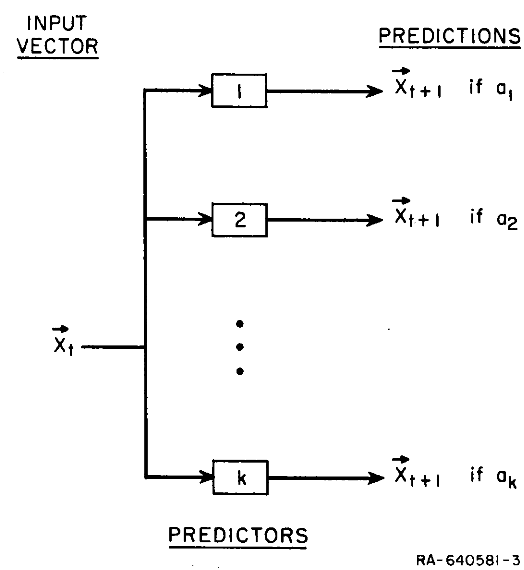

FIG. 3 PREDICTION OF FUTURE INPUT VECTORS

We can now check each of the predicted future input vectors to determine which states they indicate the automaton would be in. These are the predicted states resulting from the various actions. We must now

turn to the problem of evaluating these expected states to settle on the most desirable one. The action finally taken by the actor is that which leads to the most desirable predicted state.*

We have now transformed the problem of action selection into the problem of evaluating which of k predicted states is "closest" to the sub-goal state. "Closeness" here is not necessarily connected with physical distance but will depend upon the properties of a state-diagram. Thus if a certain action normally takes the automaton from state S_i to state S_j then these states are close. The degree of closeness depends upon the number of times in the experience of the automaton that certain actions actually did effect this transition from state S_i to S_j. The degree of "closeness" between arbitrary states should also depend upon the average number of actions required in traversing between these states. This number should be averaged over those instances in which the traversals actually occurred in the experience of the automaton.

One scheme for measuring the "closeness" between states is based on an idea originally suggested by Andreae.** One implementation of this scheme uses past experiences in traversing between states to set up a network of conductances. This network provides an analog method of computing a closeness function.

The network operates as follows: provide a number of wires (one for each state). Each time the automaton acts so that state i is followed by state j, an increment of conductance is added between the (otherwise insulated) wires number i and j. This network and the cross-conductances are illustrated in Fig. 4.

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*The associative memory can be queried again at this point to see if any of the predicted states evoke a sequence of actions that reliably leads to the sub-goal. If so, these actions can be performed; if not the predicted states must be evaluated in the manner to be explained.

**Andreae, J. H., "Stella: a Scheme for a Learning Machine," a paper presented at the 2nd I.F.A.C. Congress in Basle, Switzerland, August 1963.

After some experience in its environment the automaton will build up some connections between the various states. To measure the closeness

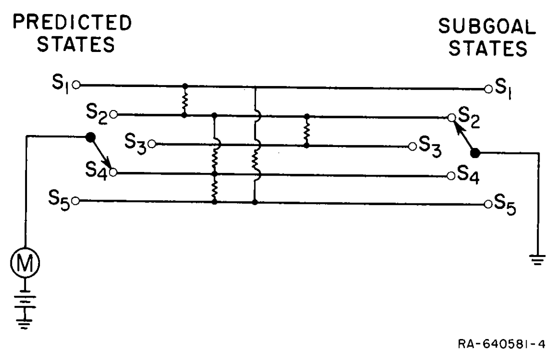

FIG. 4 STATE CLOSENESS COMPARATOR

between a predicted state and the sub-goal state, the following steps are taken:

(1) The sub-goal switch is set at the sub-goal state (grounding the corresponding wire). This action is the result of the activity of the cognitor.

(2) The state switch is set at the predicted state (connecting the corresponding wire to a voltage source).

(3) The total current provided by the source is then a measure of the effective conductance between the wires corresponding to the predicted state and the sub-goal state. Thus, it is a measure of

   (a) The number of times segments of the path between these states had been traversed before, and

   (b) The number of segments in the paths between these states.

This network for comparing closeness can then be used in conjunction with the predictors mentioned above to select the most appropriate action. The actor should decide on that action which leads to a predicted state "closest" to the sub-goal state. If the closest predicted state is not above some preset "closeness threshold," then it may be desirable to perform an action at random. This corresponds to the situation in which past experience is so limited that the actor cannot make a reasonable calculated guess and must appeal to a random action.

It must be emphasized that the above method for determining the "most appropriate" actions implies a metric for "closeness" which may or may not turn out to be desirable. Even if the implied metric is useful it may be that there exist better methods of implementation than the variable conductance network that we have described.

Assuming that this method will serve as a point of departure for future research, we will outline a flow chart for the implementation of the functions of the actor. This flow chart is shown in Fig. 5. The major subsystems used by the flow chart are summarized in Fig. 6.

The functions that must be performed by the cognitor are of essentially the same nature as those performed by the actor. Whereas the actor is capable of adaptive autonomous generation of actions, the cognitor, using similar methods, will be capable of adaptive autonomous generation of sub-goals. These sub-goals must belong to the set of states already learned by the actor. For this reason it can already be foreseen that thorough training in the "fundamentals" will be a prerequisite to the successful operation of the cognitor. There are a host of additional problems occasioned by a hierarchial structure consisting of both cognitor and actor. Intensive research is needed on such topics as the quality of communication between cognitor and actor and the appropriate levels of abstraction of the environment in cognitor and actor. These subjects will be among those considered in detail at the beginning of the proposed program.

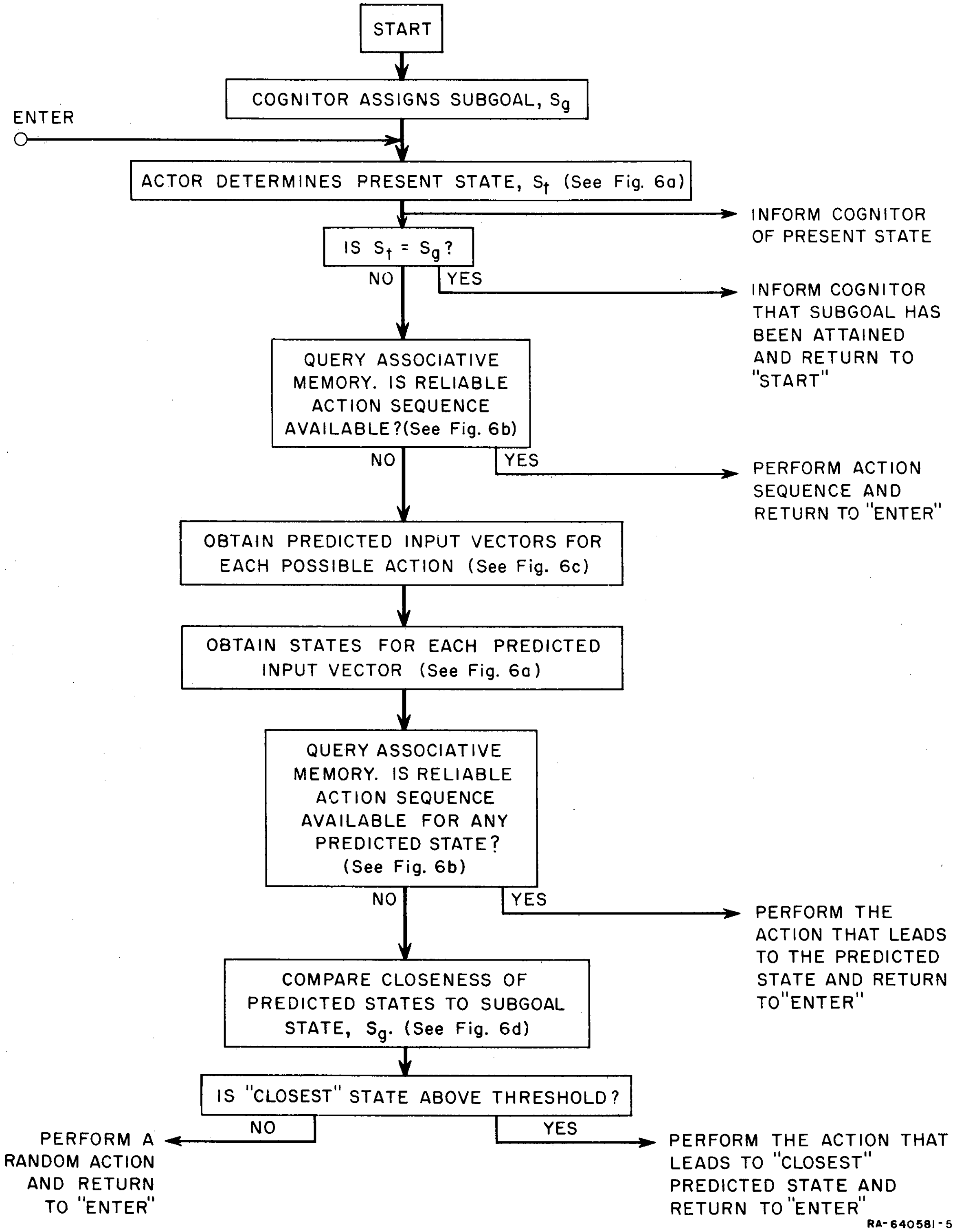

FIG. 5 FLOW CHART FOR FUNCTIONS OF ACTOR

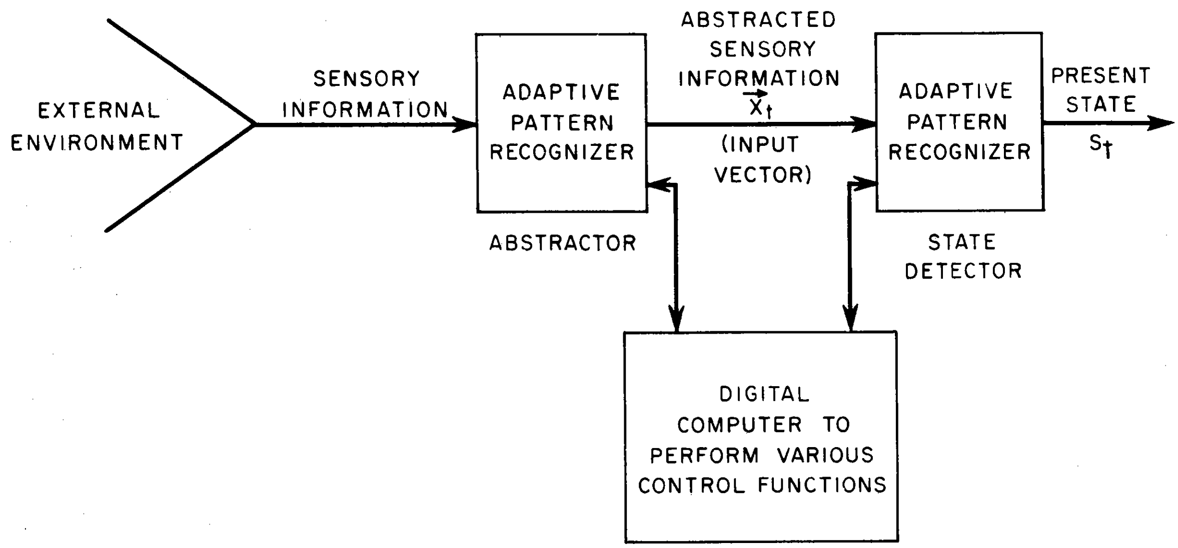

FIG. 6(a) ABSTRACTION AND STATE-DETECTION SUBSYSTEM FOR ACTOR AND COGNITOR

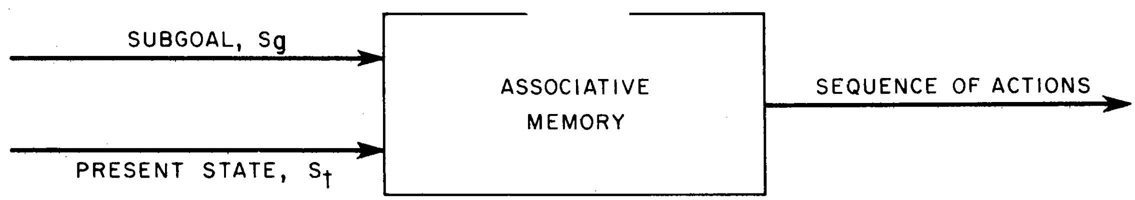

FIG. 6(b) MEMORY FOR STORAGE OF RELIABLE ACTION AND SUBGOAL SEQUENCES

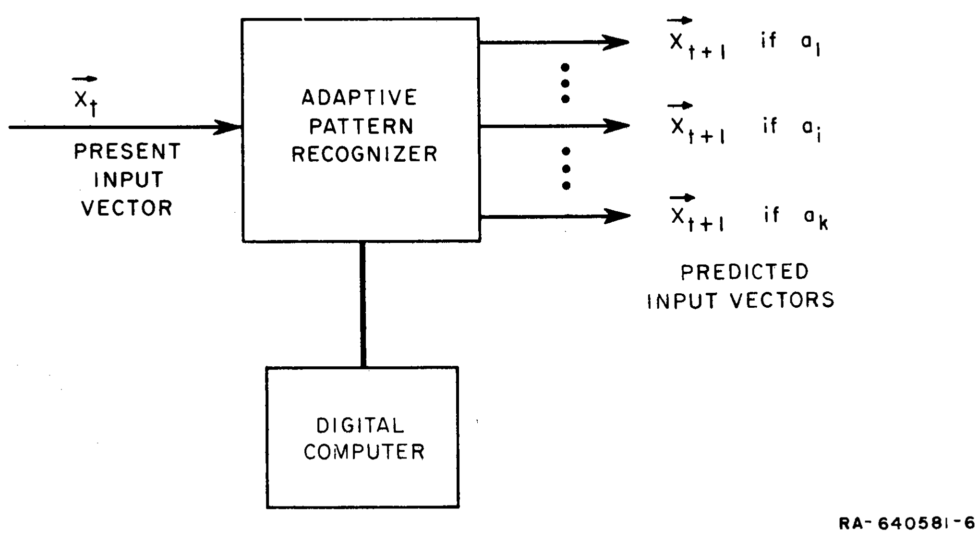

FIG. 6(c) PREDICTION SUBSYSTEM

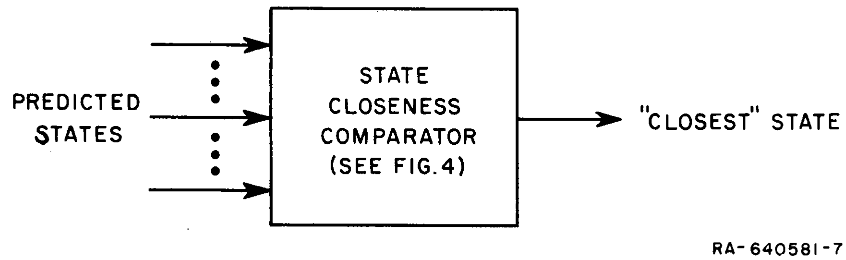

FIG. 6(d) STATE CLOSENESS COMPARISON SUBSYSTEM

D. Some Example Experiments

In this section we shall describe in detail two experiments that clearly exhibit the functions we have already discussed. A demonstration based on an experiment of similar character will be performed at the conclusion of Phase I.

The automaton in the first of the experiments to be described consists of a mobile vehicle with visual and tactile sensors. The visual sensory apparatus is a TV camera with zoom lens and associated trainable pattern recognition equipment capable of recognizing objects in the environment. The objects which the automaton must learn to recognize to achieve its goal are the walls of its enclosure, round balls within its enclosure, objects such as boxes, etc., within its enclosure, and an opening in one or more of the walls.

The tactile sensory apparatus consists of touch bars mounted around the periphery of the vehicle together with the necessary pattern recognition equipment to enable the automaton to recognize situations in which it is up against a wall, or some other object. The pattern recognition equipment for the tactile and visual modalities are common rather than separate in order to enable the automaton to perceive correlations between its visual and tactile situations.

The automaton will possess a cognitor and an actor which together will convert the abstracted sensory information into sequences of basic actions to achieve the goal. These basic actions would include, at least, the following:

(1) Remain motionless

(2) Proceed forward (or in reverse)

(3) Turn left (or right)

(4) "Kick" (to be described below)

(5) Rotate TV camera in scan mode (360° or sector scan)

(6) Adjust zoom lens to increase (or decrease) field of view.

The pattern recognition equipment and the apparatus necessary to implement the cognitor and the actor might well be located remotely from the moving vehicle. A communication link would then be necessary to couple the two parts of the automaton.

The goal of the automaton in this experiment could be to "kick" the ball through an opening in the wall. Hence the action labelled "kick." This action could be accomplished by a spring-loaded ram attached to the moving vehicle which is used to kick the ball at the appropriate time.

Let us trace through a narration of a typical demonstration of this sort. Before the demonstration could reasonably begin the automaton should have been trained on certain "fundamentals." It must have learned to recognize the ball, the wall-opening, and other objects. It must have learned the most probable consequences of various of its actions. For example, it must learn that when it kicks the ball, the ball will roll away from it (diminishing in size as it goes). It must also have learned which are some important states including, perhaps, those in the following list:

State Number	Description
1	Ball not in field of view
2	Ball in field of view but distant (or close, etc.)
3	Touching ball
4	Touching wall
5	Touching obstacle
6	Scanning
7	Between wall-opening and ball
8	On opposite side of ball from wall-opening.

It must also have learned sequences of actions that can take it from one of these states to another.

Once some of these fundamentals have been learned, the experiment can proceed. Such an experiment is still a learning experience for the automaton, and it may learn to put some of the fundamentals together in a novel way. For example, it might discover how to carom the ball off an obstacle to get it in a better position with respect to the wall-opening.

A typical demonstration would start by having the human experimenter initiate the action by providing the cognitor with the main goal. The cognitor would perhaps first set up the sub-goal, find the ball (i.e., be in a state in which the ball is in the field of view). The actor would then begin working on this sub-goal. Its first action might be to place the vehicle in a scanning mode. Once the ball is located and the first sub-goal achieved, the cognitor might set up the sub-goal, go to the ball (i.e., be in a state in which the ball is in the field of view and close). The actor would achieve this sub-goal by taking the appropriate actions. On the way it might lose sight of the ball and have to revert to the previous scanning mode again.

A way in which actions could be generated by the actor to achieve the sub-goal was outlined in the previous section. This method can be explained quite clearly using this example. Suppose the ball is ahead in the field of view and the sub-goal is to be in the state in which the ball is close. The actor must decide what to do next to bring this state about. According to the method explained in the previous section, the actor first predicts the consequences of each of the actions he might take. One of these actions is moving forward, and, if the automaton is experienced, the predicted consequence of this action is that the ball would loom larger. This consequence must be compared with the predicted consequences of other actions and a choice made about which consequence is "closest" to the goal. Suppose the other predicted consequences are: ball not in field of view, ball in field of view but smaller, and ball in field of view and the same size as before. If the automaton has had

experience in achieving this sub-goal (going to the ball) before, it should evaluate the action, go forward, as the one which would take it "nearest" to this sub-goal.

Within the general confines of the above experiment various modifications can be made to test the automaton's ability to circumvent difficulties. For example, the position of the wall-opening can be moved, the locations and number of the various obstacles can be changed, the arena can be tilted slightly, and an opponent might be added to try to prevent the automaton from achieving its goal. The exact way in which the automaton would adapt to these changes cannot be foreseen ahead of time, and some novel and surprising reactions might be observed.

The experiment involving "kicking" a ball through an opening can easily be modified to assume a more realistic flavor. This modification would constitute a second example experiment that we will now describe.

Suppose that instead of kicking a ball through an opening in the wall, the goal of the automaton is to perform an information gathering function. It is instructed to set out from home base, locate an object and transmit information about some characteristic of the object back to home base. We might suppose that the object to be located can be identified by its known characteristic color or shape; the information to be transmitted back to home base might be the unknown height of the object, for example.

The task of locating the object is far from trivial if the environment has various obstacles that may originally shield the object from view. A further interesting possibility is afforded if the terrain over which the automaton must travel is not level. A still more difficult task is created when the object can sense the automaton under specified conditions and can take countermeasures.

During initial phases of training the object might be placed in plain sight and within easy reach of the automaton. The automaton searches with its "eye," locates the object by its color, (say), and proceeds in a straight line to the object.

Next, the object might be placed in view but separated from home by a ditch. In attempting the straight line path to the object the vehicle experiences some tilting. This tilting may increase until the vehicle recognizes it as dangerous. (It may be taught what its limit is by being allowed to tip over once.) It must then seek an indirect path that is safe, and it presumably will remember where the safe crossing areas are. Another crucial bit of information which the machine can learn is that, should the desired object disappear, going to a higher elevation is in general a good tactic to bring it back into view. Eventually, when the lost object is not initially in view, a sub-goal will have been established--when in doubt, climb upward for a better view.

The functions of pattern and recognition sub-goal generation are as apparent in this experiment as they were in the ball-kicking one. Clearly, given an intelligent automaton, consisting of at least a cognitor and actor, several different varieties of experiments can be envisioned. The point of view adapted in this proposal is this: It is not crucially important which form the experiment may take. Indeed the form of the experiment(s) to be conducted during the proposed program may or may not appear realistic. The important point is that the experiment be chosen to expose the key problems basic to the development of intelligent automata. If these key problems can be solved at a general level, then applications of intelligent automata can be made to a wide variety of tasks.

V EQUIPMENTS NECESSARY FOR THE IMPLEMENTATION OF THE AUTOMATON FACILITY

A. Categories of Equipment Needed

In the previous section we put forth some suggested methods of implementing the functions to be performed by the cognitor and actor. In this section we discuss the physical hardware necessary to realize these implementations. The hardware falls into four broad categories. These are:

(1) External environment for demonstration(s), arena, walls, obstacles, emitters (sonic, IR and/or E/M), etc.

(2) Mobile vehicle motors, sensors (tactile, visual, IR, sonic, E/M), chassis, etc.

(3) Communication link between mobile vehicle and remote data processor

(4) Data processor: adaptive pattern recognizers, digital computers, storage, interface equipment.

The equipments needed in Categories 1, 2, and 3 will depend largely on the precise demonstration to be performed. A firm description of the equipment in these categories can be given only after the initial research in Phase I sheds illumination on the subject of the most appropriate demonstration(s). In any case, the total cost of the equipments in these categories should be held to only a small fraction of the cost of all of the equipments. Our desire in this program is to minimize the complexity of the equipments needed in Categories 1, 2, and 3 so that these categories do not obscure the central item of interest: the functions to be performed by the data processing equipments in Category 4.

We shall devote the rest of this section to a discussion of the data processing equipments needed.

B. Data Processing Equipments Required

Data processing functions will be performed by both the cognitor and the actor. The main subsystems of the actor were diagrammed in Fig. 6, and it is anticipated that the subsystems required by the cognitor will be essentially the same. Referring to Fig. 6(a), the cognitor and actor can probably use the same abstractor, consisting of an adaptive pattern recognition device. This device should be of a size of the same order of magnitude as that of MINOS II with preprocessor, and should be controlled by a small digital computer.

The cognitor and actor will each need a state detector. Together, these two state detectors could be implemented by a machine roughly the size of MINOS II controlled by a small digital computer. This completes the equipment needed to implement the subsystem of Fig. 6(a).

The associative memory, shown as a separate subsystem in Fig. 6(b), could probably serve both the cognitor and actor if it were large enough. The precise storage capacity needed is not known at this time. It may prove more desirable to simulate the associative memory by a small digital computer controlling serial memory units (such as disc units) than to try to obtain a real associative memory. This decision will be influenced by a number of factors, including

(1) Storage capacity required

(2) Response time required

(3) Current availability and cost of associative memories.

The predictor subsystems [Fig. 6(c)] again call for adaptive pattern recognition equipments. Here again, it is reasonable to assume that a machine similar to MINOS II could implement the prediction functions required by both the cognitor and the actor. This prediction equipment should also be under the control of a small digital computer.

The final subsystem, the State Closeness Comparator shown in Fig. 6(d), will require a matrix of adjustable conductances or the equivalent. One possible implementation of such a matrix could possibly be accomplished with existing analog storage devices. The cognitor and the actor

will each require such a matrix. The size of these matrices can be determined only after it is decided how many states should be recognizable.

In addition to the equipments discussed above for implementing the required subsystems, it will be necessary to have a medium size digital computer to control the whole process and interface equipment linking the various subsystems to the computer. The programs used to control the process would have flow charts similar to that discussed in the last section. The master control computer will require adequate memory in the form of core-storage and tape units. Also required will be a library of programs to use in conducting research experiments with the equipment.

C. Summary of Necessary Equipment

Let us sum up the equipments that have been named so far. The equipments for the external environment, the mobile vehicle, and the communication link cannot be specified until the initial research indicates the most appropriate experiment(s). This equipment will not be a major item of expense, probably amounting to only a small fraction of the total cost of equipments.

The data processing equipment needed can be generally specified now, although the research of the early part of Phase I may indicate some changes in the size and complexity of equipment needed. We propose that such changes as are mutually agreeable on these estimates for the size and complexity of the equipments be made after the initial research during Phase I. The equipments foreseen at this time are as follows:

Quantity	Description
2	Adaptive pattern recognition equipments to be used as state-detectors and predictors for cognitor and actor (to be constructed)
1	Adaptive pattern recognition equipment to be used to abstract essential information from the environment (to be constructed)
3	Small digital computers to control each of the above adaptive pattern recognition equipments (to be leased)
1	Associative memory or equivalent (to be leased or purchased)

2	State Closeness Comparators of Actor and Predictor (to be constructed)
1	Medium size digital computer to control the whole process (to be leased)
1	Interface equipments (to be constructed and purchased).

The detailed cost estimates of the above equipments are outlined later in this proposal.

VI SPECIFIC TASKS IN SUPPORT OF PHASE I OBJECTIVES

In this section we shall enumerate the tasks that would be set up to achieve the objectives of Phase I. The phasing of these tasks will be discussed at the end of this section.

A. Task A--Theoretical Studies

This task will have as its main objective the analysis and evaluation of the basic functions needed in the cognitor and actor. These functions, as discussed previously, include

(1) Pattern recognition for abstraction and state detection

(2) Prediction and modeling of the environment

(3) Autonomous sub-goal and action selection

(4) Communication between actor and cognitor.

In addition to studying the above functions, this task will be concerned with efficient methods of training the automaton so that important environmental patterns, states, and sub-goal sequences can be learned. It is to be expected that digital computer simulations will be used frequently during this task.

B. Task B--Design of Experiment(s)

This task will use the results of Task A, as they become available, to specify an appropriate demonstration and to make recommendations on the implementation of the automaton to be used in the experiment(s). Tasks A and B will have a high degree of coupling and work on both shall proceed hand-in-hand.

C. Task C--Detailed Specification and Design of Apparatus

Following the recommendations made in Task B, this task shall produce detailed specifications of the equipments needed to realize the suggested functions. This shall include all apparatus necessary in the

proposed experiment(s), including the specification of equipment (such as digital computers) to be leased or purchased, and the design of equipment to be built.

D. Task D--Construction and Check-Out of Apparatus

This task shall have as its objectives the development, construction, and check-out of all equipments needed in the proposed experiment(s). Included in this task is the successful coupling of all purchased and leased equipments (including digital computers) with the equipments to be constructed.

E. Task E--Empirical Research

This task will use the equipment that has been assembled to confirm or deny hypotheses formed in Tasks A and B. Experiments involving learned pattern recognition ability and learned autonomous sub-goal functions shall be conducted as part of this task. Any useful programs that facilitate this empirical research shall be adopted, amended, or developed as part of this task.

F. Task F--Demonstration

This task will have as its objective the successful performance of a demonstration indicating intelligent behavior on the part of the laboratory automaton. This demonstration will be of such a character that it displays both the crucial problems to which solutions have been found and those problems still in need of further research.

The phasing of the above tasks is indicated in the charts of Fig. 7. Each chart indicates the level of effort in number of professional personnel for one of the tasks. Figure 8 shows the total level of effort. The total professional effort of this program, over the three years, is 285 man-months. The level of effort during the first eighteen months is 138 man-months.

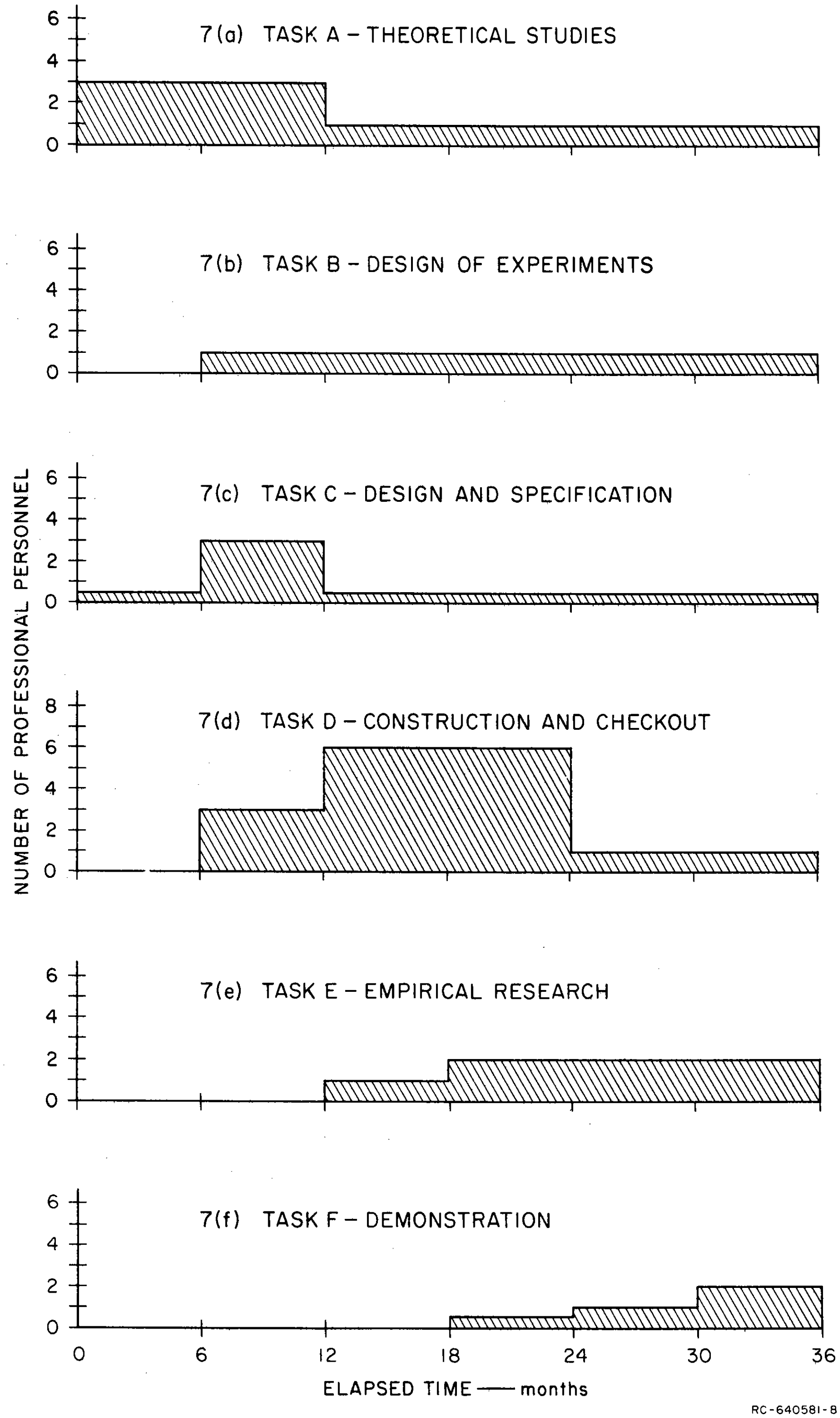

FIG. 7 PHASE I – LEVEL OF EFFORT FOR EACH TASK

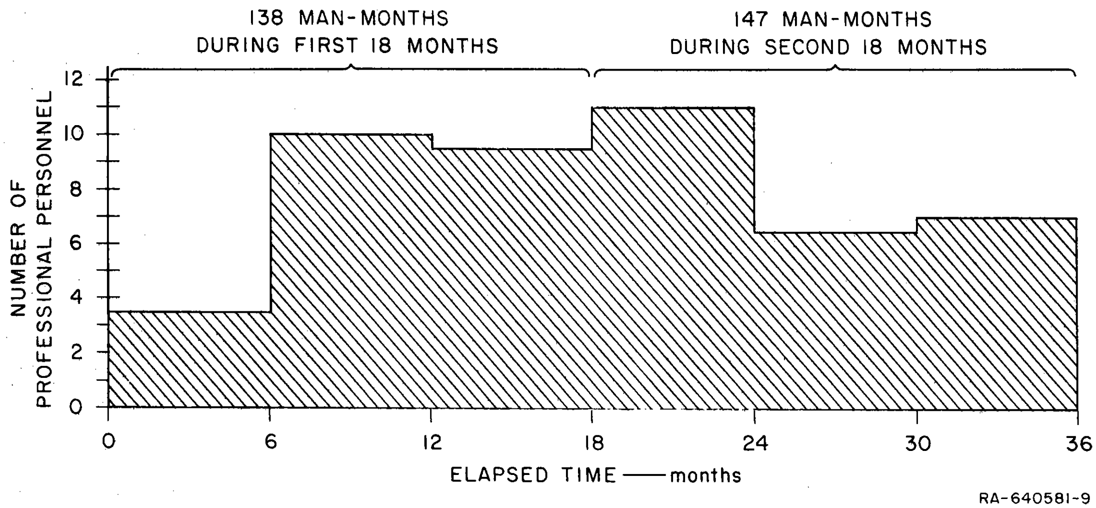

FIG. 8 PHASE I – TOTAL LEVEL OF EFFORT

VII REPORTS

Reports will be submitted in accordance with client requirements.

VIII CONTRACT FORM

It is requested that any contract resulting from this proposal be written on a cost-plus-fixed fee basis.

IX ESTIMATED TIME AND CHARGES

Attached are cost estimates for the first and the second eighteen months of the proposed three-year program.

X ACCEPTANCE PERIOD

This proposal will remain in effect until August 15, 1964. If consideration of the proposal requires a longer period, the Institute will be glad to consider a request for an extension in time.

XI QUALIFICATIONS OF STANFORD RESEARCH INSTITUTE

The Institute was founded in 1946 by the Trustees of Stanford University at the request and with the support of a group of leading West Coast industrialists. Stanford Research Institute is a separate not-for-profit corporation governed by a Board of Directors, elected by the Trustees of Stanford University. Within this framework, the Institute operates independently, and maintains its own administrative and research staff and facilities. However, there are several mutually beneficial working arrangements between the two institutions, such as the joint use of certain special-purpose facilities such as the computation center.

The Institute engages in a number of broad areas of research in engineering, economics, and the physical and life sciences, and consists of a staff of approximately 2400 people. The research study described in this proposal would be conducted primarily by the Institute's Engineering Sciences Division, with a group of researchers selected whose skills and backgrounds seem most likely to apply to the solution of the problem described in this proposal. A brief description of the work carried on in this division follows.

The Engineering Sciences Division, headed by Dr. Jerre D. Noe, is concerned with the broad aspects of information sensing, processing, and utilization, and process instrumentation and control. This includes the conception and development of advanced techniques and devices, theoretical analyses, and over-all system studies, and results where appropriate in prototype hardware fabrication of new and/or critical sub-assemblies or complete operating systems, both mechanical and electronic. These activities are carried out in several laboratories whose interests and capabilities are complementary.

1. Computer Techniques Laboratory

Field of interest in digital computer technology ranges from basic studies of network mathematics and language of computers, and studies of the

physical operation and circuit possibilities of new computer devices, to the construction of feasibility models of special-purpose machines using new techniques. Several specific areas of activity include:

(a) Logical Design and Coding. Programs concerned with formulation of new computer network design techniques and with the development of special error-correcting codes for use in data transmission.

(b) All Magnetic Logic. Multi-aperture ferrite magnetic devices in thin magnetic films are being studied to find better ways of building digital networks, using only magnetic materials and wire.

(c) Data Storage and Access. Studies are being conducted of new types of access switches, memory organization for optimal problem solving, "read-only" type memories, all magnetic access circuits for memory, and new techniques for storing information.

(d) Special Purpose Digital Systems. This area includes system studies and equipment design and fabrication for automated data entry and data reduction, automatic direction and control of data gathering, computer language and code translation, improved computer input-output methods and devices, small special-purpose computers, and digital control computers.

2. Control Systems Laboratory

Electronic, mechanical, electro-mechanical instrumentation and control for industry and government, theoretical analysis, working devices, and systems. Areas of interest include:

(a) Controls. Systems transducers, actuators, theoretical studies.

(b) Instrumentation. Sensors, automatic measurements, recording.

(c) Mechanics. Kinematics, high-speed devices, fluid mechanics, pneumatics, thermodynamics, heat transfer.

(d) Electronics. Solid-state and vacuum tube circuitry, information

theory, correlation techniques, prediction theory, sample-data systems decision circuitry.

(e) Data Processing. Input and output equipment, analog computers, and controls.

(f) Bioengineering. Studies in medical engineering, sensory communications, and bionics.

(g) Special Techniques. Engineering optics, photoelectric devices, infra-red, high vacuum techniques, automatic inspection and surveillance.

3. Applied Physics Laboratory

The theory, techniques, processes, and instrumentation for the fabrication, assembly, and utilization of extremely compact microelectronic components. Theory, development of systems and components for adaptive networks useful for learning machine applications. Design and construction of large learning machines. Specific areas of work include:

(a) Pattern Recognition. Development of machines to perform pattern recognition of graphical data, and information of similar kind. Includes applications to general character recognition problems.

(b) Learning Machines. Mathematical theory, and application to prediction, modelling, and automata.

(c) Microelectronics. Development of electron-beam machining techniques and apparatus suitable for the production of complete machines composed of very large numbers of inter-connected active elements. Applications for high-density storage and special purpose computers.

4. Systems Engineering Laboratory

The analysis, design, and evaluation of large-scale information systems. This includes applied activities looking to the generation of systems design in response to specific client needs, and basic research activities concerned with the development of improved analysis and design techniques. Work and interest is divided amongst three major areas:

(a) Data Processing Systems. The design process encompasses three phases. The user's system goals are translated into realistic technical requirements, followed by determination of a system design, and then by careful evaluation of system performance--the multiple iteration of this process providing increasingly detailed and responsive over-all system design.

(b) Man-Machine Information Systems. Equipments are being developed to perform some of the functions normally classed as mental or intelligence processes that have in the past been performed entirely by humans. Work is directed toward development of information systems devoted to improving the capabilities of these systems for performing increasingly complex functions with machine and humans operating as a highly coordinated unit.

(c) Communication Networks. This encompasses the design and utilization of communication networks, including methods for determining the connectivity, channel capacities, and network control doctrines of both store-and-forward and real-time networks. Also studied are networks in which users fall into one of several priority classes, and where the physical state of the network is subject to severe degradation.

5. Physical Electronics Laboratory

The role of this group is to integrate device and circuit research for the purpose of generating new and useful electronic sub-systems. Areas of particular interest are:

(a) Electromagnetic Propagation. Theoretical study of the interaction between fields and particles and of the modes of electromagnetic propagation.

(b) Solid State and Vacuum Devices. The study and development of devices for the generation, amplification, and detection of electromagnetic energy. Emphasis is on metal-based transistors and thin-film cathodes.

(c) Display. The storage and display of information, with emphasis on video techniques and special display devices.

(d) Electrostatic Optics. Printing and facsimile recording, including non-contact techniques and full color reproduction.

XII PERSONNEL

Key personnel will be drawn from the five laboratories comprising the Engineering Sciences Division and from the Mathematical Sciences Department. The project will be led by Dr. Nils Nilsson, Head, Learning Machines Group, Applied Physics Laboratory.

Biographies of key people follow:

Noe, Jerre D. - Director, Engineering Sciences Division

Dr. Noe holds a B.S. degree from the University of California at Berkeley, and in 1948 received the Ph.D. degree in Electrical Engineering from Stanford University.

Dr. Noe came to Stanford Research Institute from Hewlett-Packard Company, Palo Alto, where he was in the development laboratories from 1946 to 1948. For two years prior to joining this organization he was a research Associate at the Radio Research Laboratory at Harvard University. He held a similar position with the Laboratory's affiliate, American-British Laboratory in Malvern, England, during 1944 and 1945.

In his present position, Dr. Noe administers Institute laboratories in computer techniques, applied physics, physical electronics, control systems, and systems engineering.

He is a member of Sigma Xi, Eta Kappa Nu, Tau Beta Pi, and the Institute of Electrical and Electronics Engineers.

Dr. Noe served as a member of the Joint Computer Conference Committee in 1953-1954. In 1954 he was appointed to serve on the National Administrative Committee of the IRE Professional Group on Electronic Computers. He became National Chairman of the PGEC for 1956-1957. Dr. Noe served as Chairman of the Technical Program Committee for WESCON 1963.

Nilsson, Nils J. - Head, Learning Machine Group, Applied Physics Laboratory

In August 1961 Dr. Nilsson joined the staff of Stanford Research Institute, where he has participated in and led research in pattern recognition and self-organizing machines. He has taught courses on learning machines at Stanford University and at the University of California, Berkeley. He expects to publish soon a monograph describing recent theoretical work in learning machines.

Dr. Nilsson received an M.S. degree in Electrical Engineering in 1956 and a Ph.D degree in 1958, both from Stanford University. While a graduate student at Stanford, he held a National Science Foundation Fellowship. His field of graduate study was the application of statistical techniques to radar and communication problems.

Before coming to SRI, Dr. Nilsson completed a three-year term of active duty in the U. S. Air Force. He was stationed at the Rome Air Development Center, Griffiss Air Force Base, New York. His duties entailed research in advanced radar techniques, signal analysis, and the application of statistical techniques to radar problems. He has written several papers on various aspects of radar signal processing. While stationed at the Rome Air Development Center, Dr. Nilsson held an appointment as Lecturer in the Electrical Engineering Department of Syracuse University.

Dr. Nilsson is a member of Sigma Xi, Tau Beta Pi, and the Institute of Electrical and Electronics Engineers.

Rosen, Charles A. - Manager, Applied Physics Laboratory

Dr. Rosen received a B.E.E. degree from the Cooper Union Institute of Technology in 1940. He received an M. Eng. in Communications from McGill University in 1950, and a Ph.D. degree in Electrical Engineering (minor, Solid-State Physics) from Syracuse University in 1956.

Since December 1959 Dr. Rosen, as Manager of the Applied Physics Laboratory, has been engaged in the technical planning and build-up of

facilities and personnel to carry out major projects in microelectronics and learning machines.

In 1940-1943 he served with the British Air Commission as a Senior Examiner dealing with inspection, and technical investigations of aircraft radio systems, components, and instrumentation. During the period 1943 to 1946, he was successively in charge of the Radio Department, Spot-Weld Engineering Group, and Aircraft Electrical and Radio Design of Fairchild Aircraft, Ltd., Longueuil, Quebec, Canada. From 1946 to 1950 he was a co-partner in Electrolabs Reg'd., Montreal, in charge of development of intercommunication and electronic control systems. In 1950 he was employed at the Electronics Laboratory, General Electric Company, Syracuse, New York, where he was successively Assistant Head of the Transistor Circuit Group, Head of the Dielectric Devices Group, and Consulting Engineer, Dielectric and Magnetic Devices Subsection. In August 1957 Dr. Rosen joined the staff of Stanford Research Institute where he helped to develop the Applied Physics Laboratory.

His fields of specialty include learning machines, dielectric and piezoelectric devices, electro-mechanical filters, and a general acquaintance with the solid-state device field. He has contributed substantially as co-author to two books, Principles of Transistor Circuits, R. F. Shea, editor (John Wiley and Sons, Inc., 1953) and Solid State Dielectric and Magnetic Devices, H. Katz, editor (John Wiley and Sons, Inc., 1959).

Dr. Rosen is a Senior Member of the Institute of Electrical and Electronics Engineers, a member of the American Physical Society, and the Scientific Research Society of America.

Rice, Philip J. - Manager, Physical Electronics Laboratory

Dr. Rice received an A.B. degree in Physics from Brown University in 1940 and an M.S. degree in Physics from Case Institute of Technology in 1942. He received an M.S. degree in 1946 and a Ph.D. degree in 1948, both in Physics, from Yale University. The subject of his dissertation was "Design of a Linear Electron Accelerator."

From 1942 to 1945 Dr. Rice was a staff member of the Radiation Laboratory at the Massachusetts Institute of Technology where he helped to design, build, and test large ship-mounted microwave early-warning radar systems for the Navy, including field work at various naval bases and aboard ships. From 1948 to 1952 he was employed by the Bell Telephone Laboratories in New York City and Murray Hill, New Jersey, where he worked on the design of microwave tubes, including triodes and traveling wave tubes.

Dr. Rice joined the staff of Stanford Research Institute as a Supervisor in 1952 in the Electron Tube Laboratory, and since then has been engaged in electron tube design and development. In 1955 he was appointed Manager of the Electron Devices Laboratory; and in 1962 was appoined Manager of the Physical Electronics Laboratory.

His fields of specialty include research in microwave triodes, traveling wave tubes, high current guns, beam focusing, storage tubes, and electrostatic writing tubes. He has written articles for technical journals on electronic accelerators, electron beam focusing structures, and electrostatic printing. Patent assignments are in the field of traveling wave tubes.

Dr. Rice is a Senior Member of the Institute of Electrical and Electronics Engineers, and a Member of the American Physical Society and the Scientific Research Society of America. In 1963 he received the IEEE Prize Award by Vladimir K. Zworykin, for the development of techniques and equipment for fixing televised images on paper.

Ablow, Clarence M. - Head, Applied Mathematics Group
Associate Manager, Mathematical Sciences Department

Dr. Ablow received, in 1951, a Ph.D. degree in Applied Mathematics from Brown University. He then became a Research Specialist at the Boeing Airplane Company, engaged in Applied Mathematics, and remained there until he joined the staff of Stanford Research Institute in 1955. At the Institute, he has been concerned with problems in continuum mechanics,

heat transfer, and chemical kinetics. This work has led to a number of publications in Technical journals as listed below.

Dr. Ablow is a member of Phi Beta Kappa, Sigma Xi, the American Mathematical Society, the Mathematical Association of America, and the Society for Industrial and Applied Mathematics.

Publications:

With J. L. Brenner, "Roots and Canonical Forms for Circulant Matrices," Trans. Amer. Math. Soc., Vol. 107, No. 2 (May 1963).

"The Strength of Seismic Shock in an Elastic Earth Under Blast Loading," Proceedings, Fourth Natl. Congress Appl. Mechanics, Berkeley, June 1962.

With Henry Wise, "Diffusion and Heterogeneous Reaction, IV. Effects of Gas-Phase Reaction and Convective Flow," J. Chem. Phys., Vol. 35, No. 1 (July 1961).

With M. W. Evans, "Theories of Detonation," Chem. Revs., Vol. 61, No. 2 (April 1961).

"Wave Refraction at an Interface," Quart. Appl. Math., Vol. XVIII, No. 1 (April 1960).

With C. L. Perry, "Iterative Solutions of the Dirichlet Problem for $\Delta u = u^2$, J. Soc. Indust. Appl. Math., Vol. 7, No. 4 (December 1959).

With Henry Wise, "Diffusion and Heterogeneous Reaction. I. The Dynamics of Radical Reactions," J. Chem. Phys., Vol. 29, No. 3 (September 1958).

With S. E. Rea, "Transient Air Temperatures in a Duct," Trans. Amer. Soc. Mec. Engrs., Vol. 79, No. 7 (October 1957).

With Henry Wise, "Burning of a Liquid Droplet. III. Conductive Heat Transfer Within the Condensed Phase During Combustion," J. Chem. Phys., Vol. 27, No. 2 (August 1957).

With Georges Brigham, "An Analog Solution of Programming Problems," J. Operations Res. Soc., Vol. 3, No. 4 (November 1955).

Merritt, Philip E. - Head, Electronics Group, Control Systems Laboratory

Dr. Merritt received a B.S. degree in Electrical Engineering from the University of California in 1952. He was then granted an Industrial Electronics Fellowship from the Research Laboratory of Electronics of the Massachusetts Institute of Technology where he received an M.S. degree in 1953. In 1960 he received a Ph.D. degree from Stanford University, also in Electrical Engineering.

Dr. Merritt joined the staff of Stanford Research Institute in 1953 and was project leader for the development of pattern recognition systems and numeral-reading techniques used in the ERMA electronic system for banking. In 1960 he became head of the Electronics Group and has been supervising research in the application of analog computer techniques to industrial problems, the use of the quadrupole mass spectrometer for making rapid chemical analyses, and development of such special medical instrumentation as a fetal heartbeat monitor, a blood-pressure transducer, and a vectorcardiograph for clinical use.

Under his direction, the Electronics Group is participating in a range of industrial and military problems including control systems design, data acquisition, and processing systems; biomedical engineering; bionics; process control; automatic control systems; advanced magnetic core-transistor circuitry; and magnetic character reading.

Dr. Merritt is a member of Sigma Xi, Tau Beta Pi, the Research Society of America, and Eta Kappa Nu.

Adams, Milton B. - Assistant Manager, Computer Techniques Laboratory

Mr. Adams received a B.S. degree in Electrical Engineering from the University of Florida in 1943. From 1943 until 1945 he was a Research Associate at the Radio Research Laboratory at Harvard University and the American-British Laboratory at Malvern, England, both of which were engaged in radar countermeasure research. His activities while at Harvard and in England included design, specification, and field testing of radar countermeasures, transmitters, receivers, and special purpose intercept

systems for use by the U.S. Navy and Air Force. He acted as leader of the Transmitter Group at American-British Laboratory during a portion of 1945. While at Philco Corporation from 1945 to 1947 he was concerned with television relay system and television receiver design. In 1947 he became a Research Assistant at Stanford University while attending the Graduate School of Electrical Engineering. In 1949 he received the degree of Engineer in Electrical Engineering, and joined the staff of Stanford Research Institute.

While at the Institute he has been concerned with UHF television receiver design, radar system problems, railroad signaling problems, and since 1951 has been a member of the Computer Techniques Laboratory. He has worked on the design of magnetic drums, magnetic tape transports, and high-speed printers and printer systems for use with digital computers. As head of the Special Projects Group in the Computer Techniques Laboratory he has directed development of major portions of a military reconnaissance system, including the complete ground data-handling computer and display system and an airborne digital logic system. He has also supervised a number of reliability studies of satellite and ground-based military systems. His most recent responsibility is that of Assistant Manager for the Computer Techniques Laboratory.

Mr. Adams is a member of the American Association for the Advancement of Science, the Association for Computing Machinery, the Institute of Electrical and Electronics Engineers, the Scientific Research Society of America, Sigma Tau, and Sigma Xi.

Brain, Alfred E. - Research Physicist, Applied Physics Laboratory

Dr. Brain received a B.Sc. degree in 1943, an M.Sc. degree in 1948, and a Ph.D. degree in 1952, all in Physics from the University of Sheffield, England. From 1943 to 1946 he served at the Royal Aircraft Establishment, Farnborough, as a Junior Scientific Officer, developing anti-jamming devices and rebuilding captured radar equipment. During the period of 1948 to 1949 he was a Circuit Engineer at the E.M.I. Research Laboratories,

Middlesex, England, working on multistage, wideband video amplifiers for high definition television. In 1949 Dr. Brain joined the staff of the Department of Physics of Sheffield University, as Ellison Research Fellow. He carried on research on the magnetic properties of semiconductors and supervised undergraduate teaching laboratories. In 1952 he returned to the E.M.I. Laboratories as a Physicist to set up a section to do work in solid-state physics.

In 1956 he became a Physicist in the Electronics Laboratory of the General Electric Company in Syracuse, working on thin magnetic films, photocells, and the phase correction of delay lines.

In December 1958 Dr. Brain joined the staff of Stanford Research Institute, where he has been engaged in the study of learning machines, and their application to adaptive parallel processing systems capable of performing pattern recognition. Since April 1960 he has been project leader on the graphical data processing research study for the Signal Corps for which the learning machines MINOS I and MINOS II have been constructed.

Dr. Brain is an Associate Member of the British Institute of Electrical Engineers and a Senior Member of the Institute of Electrical and Electronics Engineers.

Duda, Richard O. - Research Engineer, Applied Physics Laboratory

Dr. Duda received a B.S. degree in 1958 and an M.S. degree in 1959, both in Electrical Engineering, from the University of California at Los Angeles. In 1962 he received a Ph.D. degree from the Massachusetts Institute of Technology, where he specialized in network theory and communication theory.

Between 1955 and 1958 he was engaged in electronic component and equipment testing and design at Lockheed and ITT Laboratories. From 1959 to 1961 he concentrated on control system analysis and analog simulation, including adaptive control studies for Titan II and Saturn C-1 boosters, at Space Technology Laboratories.

In September 1962 Dr. Duda joined the staff of Stanford Research Institute, where he has been working on problems of preprocessing for pattern recognition and on the theory and applications of learning machines.

Dr. Duda is a member of Phi Beta Kappa, Tau Beta Pi, Sigma Xi, and the Institute of Electrical and Electronics Engineers.

Forsen, George E. - Research Engineer, Applied Physics Laboratory

Mr. Forsen received both the S.B. and the S. M. degree in Electrical Engineering from the Massachusetts Institute of Technology in 1957, and the degree of Electrical Engineer from MIT in 1959.

He was employed part time in 1954-1956 by the General Electric Company, on the Cooperative Plan with MIT. While with GE he worked on non-destructive testing methods, and measurement techniques for heat flow in power transistors.

In 1958-1959 he was a Research Assistant and staff member of the Communications Biophysics Group, Research Laboratory of Electronics at MIT. There he designed electronic instrumentation for the study of neuroelectric and psychophysical phenomena related to nervous systems. From 1957 to 1959 he was also employed by the Electrical Engineering Department of MIT as a Teaching Assistant.

In October 1959 Mr. Forsen joined the staff of Stanford Research Institute. At the Institute he is currently engaged in the study of neuron-like devices, and adaptive, cognitive systems, He has authored several patents and papers in these fields.

Mr. Forsen is a member of Sigma Xi.

Hall, David J. - Research Engineer, Applied Physics Laboratory

Mr. Hall joined the staff of Stanford Research Institute in April 1962. He received a B.S. degree in Electrical Engineering from the University of Witwatersrand, Johannesburg, South Africa in 1954, and an M.S. degree in Electrical Engineering from London University in 1957.

From 1957 to March 1962 Mr. Hall was Assistant Chief Engineer for F. G. Slack & Company in Johannesburg, where he worked with quotations, design, and the development and production of a specialized range of industrial electronic products. He is particularly interested in solid-state switching, relay logic, psychometric methods, shaft signalling, mining communication systems, and safety devices with fail-safe characteristics; also in industrial applications of radio isotopes, particularly for density control.

Mr. Hall was in the South African military service from 1950 to 1954, serving as a full lieutenant, with duties in radar, sound ranging, surveying of gun positions, etc. He was awarded the Swan Memorial Scholarship in London (1956) and the British Admiralty Research Grant (1956). He reads, writes, and speaks Afrikaans, and reads both French and German.

Munson, John H. - Research Physicist, Applied Physics Laboratory

Since joining SRI in 1963 Dr. Munson has been engaged in learning machine research and applications. His activities have included the exploration of combined digital computer-learning machine systems and their potential application for advanced automata.

Dr. Munson received a B.Sc. degree with honors from the California Institute of Technology in 1960. He received an M.A. degree in 1962 and a Ph.D. degree in 1964 (to be formally conferred in June 1964), both from the University of California at Berkeley, in the field of Physics. He held a National Merit Scholarship award as an undergraduate, and a National Science Foundation fellowship as a graduate student.

In his doctoral research in nuclear physics, Dr. Munson participated in the design and use of a computer-connected system for measurements on bubble-chamber film. He was primarily engaged in machine-language, FORTRAN, and hybrid computer programming, real-time man-machine systems, and graphical pattern recognition. This past experience has also included work in reactor physics, data analysis, and analog computers.

Dr. Munson is a member of Tau Beta Pi.

Shapiro, Elmer, B. - Senior Research Engineer, Systems Engineering Laboratory

Mr. Shapiro's interests are in the synthesis and analysis of digital information processing systems and switching systems for communication networks.

He joined the staff of Stanford Research Institute in April 1960 and has led a project concerned with the development of new and advanced techniques for designing and analyzing communication networks. This has involved studies of various switching methods (such as circuit switching and store and forward switching), of network congestion phenomena and traffic routing and control doctrines. He has also served on a DOD switching committee that studied and evaluated several major, military developmental switching systems.

Before joining the Institute, Mr. Shapiro was a Member of the Technical Staff at the Bell Telephone Laboratories during the periods 1953 to 1955 and 1957 to 1960. At BTL he supervised a group responsible for the planning and development of data trunks, including signaling and supervision facilities. Prior to that, he was responsible for the system planning of maintenance and error control for a developmental, solid-state data processor. During his early years at BTL, he participated in the logical design of the Tradic computer (an airborne digital machine) and the design of high-output transistor pulse regenerative amplifiers.

During the period 1955 to 1957, he was on active duty in the U. S. Army at the Computing Laboratory of the Ballistic Research Laboratories (BRL), Aberdeen Proving Grounds. At BRL he served as an electronic engineer on the engineering staff of the Ordvac computer, concerned with the operation and maintenance of the system. He was also responsible for the logical and circuit design (a mixture of solid-state and vacuum tube) of control equipments made necessary by the installation of an enlarged core memory.

During his off-duty hours during 1957, he served as a full-time licensed engineer of the newly formed commercial AM station, WAMD, in

Aberdeen, Maryland. At WAMD he participated in the assembly of the transmitter and studio equipment, becoming responsible for the station's operation during the FCC certification tests and subsequent commercial operation.

Mr. Shapiro received a B.S. degree from the Illinois Institute of Techology in 1952 and an M.S. degree from Stanford University in 1953, both in Electrical Engineering. He completed the BTL Communications Development Training Program in 1958.

Mr. Shapiro is a member of the Association for Computing Machinery, the Institute of Electrical and Electronics Engineers, and the IEEE Professional Technical Group on Electronic Computers.

Whitby, Oliver W. - Staff Scientist, Engineering Sciences Division

In 1949 Dr. Whitby joined the staff of the Engineering Division of Stanford Research Institute. From 1950 until 1955 he was responsible for the broad system planning for the ERMA automatic bookkeeping system developed at the Institute for the Bank of America. In 1955 he headed a group charged with doing technical program planning for the computer and for the Control Systems Laboratories of the Engineering Division. In 1956 he became Manager of the General Systems Department, carrying out systems engineering for problems that employ computers, communication networks, and control elements.

In this capacity he was responsible for the close technical direction of projects in the following areas: automatic airline reservation systems, banking automation, information retrieval system design, battlefield instrumentation, communication network research, and ELINT data processing. He has also actively participated in the technical work of several of these projects. During the two years that the General Systems Department (now the Systems Engineering Laboratory) worked on technical communication problems for the Communications Requirements Study for Command and Control (Contract DA 36-039 SC-76481), Dr. Whitby acted as liaison with the part of that study oriented toward military

requirements. In this role he participated in numerous discussions about the formulation of technical requirements from military roles and missions.

In June 1961 Dr. Whitby was appointed a Staff Scientist in the Division in order to allow him to take on broader technical responsibilities in his field of systems engineering. He has recently been occupied with the problem of automating action selection in a large manufacturing corporation that makes a great many different products in a far-flung group of factories. On this project he has concerned himself particularly with the question of fitting the manufacturing schedule (action selection) to the market potential (analogous to the threat constraint) and to the manufacturing capabilities (resources) and with the data processing and information gathering techniques applicable to the inherent problems. An especially important feature of the broad system design conceived on this project was the linking and integration of the human decision maker and the data processing computers.

Dr. Whitby received a B. Eng. degree from McGill University in 1938. In 1940 he received an S. M. degree and in 1949 an S. D. degree, both in Communication Engineering from Harvard University.

Dr. Whitby is a Senior Member of the Institute of Electrical and Electronics Engineers, and an associate member of the Operations Research Society of America. In 1954-1955 he was the IRE representative on the Joint Computer Conference Committee and in 1955 was General Manager of the Western Joint Computer Conference.

Burch, G. Howard - Research Engineer, Computer Techniques Laboratory

Mr. Burch received a B.S. degree in Physics in 1951 and an M. S. degree in Electrical Engineering in 1952, both from Stanford University.

While attending Stanford he worked in the summer at Anchorage, Alaska, as a radio broadcast station engineer and an aircraft radio mechanic for Alaska Airlines, Inc.

From 1952-1954 he was a Servo Engineer with Dalmo Victor Company, San Carlos, California, where his work involved the design of electronic portions of servo systems and the development of entire systems.

Mr. Burch joined the staff of Stanford Research Institute in October 1954. For the first half year he was engaged in work on transistor circuits for color television. He spent a year working on the test program for the ERMA project, followed by several months designing transistor circuits for computers.

For over three years he led a project team engaged in the development of a portion of a large military reconnaissance system. His responsibility included the system study, design, construction, and testing of airborne automatic control equipment. Portions of this equipment utilized a stored program and incorporated both magnetic drum and magnetic core memories.

Following participation in a feasibility study for a special-purpose digital calculator, he has been engaged in system planning and detailed design of special-purpose data processing equipment for use in radio propagation research. His latest assignment has involved the design of interface equipment to couple the MINOS II adaptive pattern recognition system to a small digital computer.

Goldberg, Jacob - Senior Research Engineer, Computer Techniques Laboratory

Mr. Goldberg's present work is in the design of computer systems with high computation rate, especially those comprised of logic networks in which inter-element propagation time is significant.

Mr. Goldberg received a B.S. degree from the University of California in 1950 and an M.S. degree from Stanford University in 1954, both in Electrical Engineering. He joined the staff of Stanford Research Institute in January 1951. In 1951, he developed a noise generator and power monitor for an experimental radar. From 1952 to 1956, he contributed to the logical design of the ERMA computer. Several patent assignments have resulted from this work, relating to computer logical circuit design, including sorting, computer input checking, magnetic tape recording, and control. In 1957 he worked on a programming plan for a commercial version of the ERMA computer.

In 1958 he was a Research Fellow at the Weizmann Institute of Science in Israel, where he designed and built a transistorized magnetic-tape printing buffer.

In 1960-1961 he led a project which studied the design of a special memory for a data retrieval system in which all items in a file are tested simultaneously. This study resulted in a design for a special document index retrieval machine based on a novel memory structure and employing specially designed codes and search algorithms. A pilot version of this machine was subsequently built by the laboratory staff.

In 1962-1963 he led a project which studied the application of logical redundancy to improving the reliability of digital systems. The major emphasis was on developing practical techniques for fault detection and correction at low cost. Several efficient schemes were developed, based on error-correcting codes, for correction of faults in groups of logical circuits and in memory access and data circuits.

He is a member of the Institute of Electrical and Electronics Engineers, the IEEE Professional Technical Group on Electronic Computers, the Scientific Research Society of America, and the Association for Computing Machinery.

Masher, Dale P. - Senior Research Engineer, Computer Techniques Laboratory

Mr. Masher received an A.B. degree in Engineering Science and Applied Physics from Harvard University in 1951 and an S.M. degree in Electrical Engineering from the Massachusetts Institute of Technology in 1953. While holding a two-year teaching fellowship at MIT, he was responsible for both laboratory and classroom instruction in electronics, measurements, and circuit theory.

From 1953 until 1955 Mr. Masher was a member of the Technical Staff of Bell Telephone Laboratories. During this period he participated in the logical design of the first transistorized airborne computer; performed studies for the characterization of high-frequency transistors; and developed specialized transistor circuitry for high-temperature reading of magnetic drums.

In 1955-1957 he served in the U. S. Army, attached to the Solid State Devices Branch of the Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey. He was Chief Project Engineer on several Industrial Preparedness Study contracts for the development and production of switching transistors. Under these contracts he was responsible for the guidance of the device engineering as well as the evaluation and specification of each type.

In 1957 Mr. Masher joined the staff of Stanford Research Institute as a member of the Computer Techniques Laboratory. In this position he has had continuing experience in the design of solid-state logic and gate circuits, and corresponding experience in logic system design using such circuits. He had prime responsibility for the development of logic circuitry for a large military data processing system, and authored those sections of a special technical report entitled "Transistor Logic Circuit Design for the AN/ULD-1 System" which dealt with the actual circuit design. He wrote a related article entitled, "The Design of Diode-Transistor NOR Circuits," which was published in the March 1960 issue of the IRE Transactions on Electronic Computers. His responsibilities have further included the development of a complete magnetic-tape-to-magnetic-tape conversion system and the design of read, write, and selection circuitry for several transistor driven, magnetic core memories. He has performed research in tunnel diode circuits resulting in a patent application on a tunnel diode NOR/NAND circuit. Following this he was engaged in low-cost circuit studies related to linear-input or majority logic, and studies of integrated circuit techniques. He also was responsible for the circuit and logical design of portions of the MIRF associative memory (being developed for Rome Air Development Center). His most recent assignment is in the area of digital processing of analog data as well as analog-ditial conversion technology.

Mr. Masher is a member of Phi Beta Kappa, Sigma Xi, the Institute of Electrical and Electronics Engineers and the IEEE Professional Groups on Circuit Theory, Electron Devices, and Electronic Computers.

Miller, Stephen W. - Research Engineer, Computer Techniques Laboratory

Mr. Miller's current efforts are directed toward the development of techniques for the design of memory and access systems which improve the performance of digital computers and data processing systems.

Mr. Miller became a Research Engineer in the Computer Techniques Laboratory in July 1956. Since that time he has served as project leader on studies of devices and techniques available for the design of special memory systems for both commercial and government sponsors. He has been project leader on the development of special data acquisition equipment to provide the magnetic tapes for direct computer input from real-time data sources. He has contributed to the design, construction, and testing of several digital systems including ERMA (a large banking computer system) and AN/ULD-1 (an electronic reconnaissance system).

He has been on the staff of SRI since June 1949. Prior to 1956, he served as head of the Electronic Instrumentation Group of SRI's Poulter Laboratories. This group was responsible for the design, construction and end use of electronic systems involved in the control, measurement, and analysis of physical experiments studying explosives. Previously he was responsible for the instrumentation used in seismic investigations by SRI's Department of Geology and Geophysics.

He received a B.S. degree in Physical Science from Stanford University in 1949. Mr. Miller is a member of the Scientific Research Society of America, the Institute of Electrical and Electronics Engineers, and the IEEE Professional Technical Group on Electronic Computers. He is lecturer in Electronic Instrumentation at Foothill College.

Eige, John J. - Research Engineer, Control Systems Laboratory

Mr. Eige received a B.S. degree from Iowa State College in 1953 and an S. M. degree from the Massachusetts Institute of Technolgoy in 1955, both in Mechanical Engineering. After attending Iowa State College, he was a Research Engineer for the Fisher Governor Company, Marshalltown, Iowa. While at Massachusetts Institute of Techology he was a Research Assistant in the Mechanical Engineering Laboratory and in the Dynamic

Analysis and Control Laboratory. During 1955 to 1957 he served as a lieutenant in the Corps of Engineers of the United States Army. In May 1957 Mr. Eige joined the staff of Stanford Research Institute where he has been engaged in fluid mechanics and dynamic instrumentation problems.

Project areas have included an instrumented air gun to investigate controlled impact printing, improved methods of valving process fluids, analog simulation of electromechanical systems, analysis of an external blood-pressure transducer, and instrumentation of a high-precision rocket test stand. Other project experience includes leadership of three projects involving the modulation of hydraulic power by the direct action of electric fields upon dielectric fluids.

His fields of specialty are fluid-powered and electromechanical instrumentation and control systems. He is co-author of several patents pending in these fields.

Mr. Eige is currently investigating and devising pneumatic logic and control elements.

Mr. Eige is a member of Tau Beta Pi, Sigma Xi, and the American Society of Mechanical Engineers and a Senior Member of the Instrument Society of America.

Fraser, Edward C. - Research Engineer, Control Systems Laboratory

Mr. Fraser attended the Worcester Polytechnic Institute of Worcester, Massachusetts, where he received his B.S. degree in Electrical Engineering in 1958. Following his graduation, Mr. Fraser did graduate work at the Massachusetts Institute of Technolgoy, receiving his M.S. in September 1960. He is presently working toward a Ph.D. at Stanford University.

Prior to joining the staff of Stanford Research Institute in October 1960, his experience included the analysis of aircraft electrical-power systems; a high-power servo-drive system for a radar antenna; and the development of a high-speed, high-current drive scheme for computer

memory cores. His most recent work at Lincoln Laboratory, M.I.T., was on an automatic missile-tracking system requiring design of an optimum predictor using a digital computer as a design tool for the later design of an optimum analog tracker.

At the Institute, Mr. Fraser has worked on projects including the design of an adaptive controller for chemical processes; nonlinear application of semiconductor devices to obtain linear power amplification, including analysis of signal waveshapes involved; analysis of the control requirements of a 50-BEV linear electron accelerator; and the application of analog-computation techniques to the solution of non-linear, time-varying differential equations. His areas of specialization are nonlinear and adaptive systems.

Mr. Fraser is a member of Tau Beta Pi, Eta Kappa Nu, Sigma Xi, and the Institute of Radio Engineers, and also the American Institute of Electrical Engineers.

Peschon, John - Research Engineer, Control Systems Laboratory

Dr. Peschon received his B.S. degree in Engineering from the École Supérieure de'Électricité in Paris in 1956; an M.S. degree in Electrical Engineering from the University of Illinois in 1957; and a Ph.D. degree in Electrical Engineering in the area of control system synthesis with particular emphasis on time-varying systems, from Stanford University in 1961. While at Stanford he was a Research Assistant in the Electronics Research Laboratory, participating in control systems research. In addition, he taught a course in servomechanisms for the Department of Electrical Engineering.

In October 1959, Dr. Peschon joined the staff of Stanford Research Institute, where he contributed to projects in data transmission by ultrasonic carriers, high-speed electrohydraulic systems, and application of analog computers to engineering problems including antenna designs, dynamics of long railroad trains, instrumentation systems, and special-purpose simulators.

During 1961 and 1962, Dr. Peschon acted as a scientific consultant to the Organization of Economic Cooperation and Development (OECD), Paris, in the field of computers and automatic systems, and to Stanford Research Institute. He returned to SRI's Control Systems Laboratory in 1963, where his major field of interest is the synthesis of complex automatic systems, including adaptive and learning systems. He maintains a part-time consulting appointment with OECD.

Dr. Peschon's publications include "A Modified Form of the Mellin Tranform and Its Application to the Optimum Final Value Control Problem," Proceedings of the Symposium on Active Networks and Feedback Systems (1960); "On Timesharing of Control System Components," (with W. H. Horton), IRE Transactions on Automatic Control (July 1962); "Note on Nth Order Single-Variable Optimum Relay Controls" and "The Timesharing of Dynamic Components in Control Systems and Analog Computers," in Journées d'Études sur le Contrôle Optimum et les Systèmes Non Linéaires, 13-16 June 1962 (1963); and Disciplines and Techniques of Systems Control, which Dr. Peschon edited (Ginn and Co., Boston, in press).

Novikoff, Albert B. J. - Research Mathematician,
Mathematical Sciences Department

In June 1958 Dr. Novikoff joined the staff of Stanford Research Institute, where he has been working on probability applications to antenna measurements, theoretical network analysis, equipment location, and classical mechanics, signal discrimination, and character recognition.

In 1961 he was for the third summer an invited lecturer at the Intensive Course in Random Processes given at the University of Michigan, and participated in the Second Symposium on Self-Orgnaizing Systems at the University of Illinois.

Dr. Novikoff received an A.B. degree from Brown University in 1945 and a Ph.D. degree from Stanford University in 1949, both in Mathematics. He was an Atomic Energy Commission Pre-Doctoral Fellow in Mathematics. From 1950 to 1952 he was an Instructor of Mathematics at Johns Hopkins

University. In 1952 he became a Research Associate in the Radiation Laboratory of that university,where his work included the applications of probability and Fourier methods to noise problems and also the study of signal analysis. From 1956 to 1958 he was an Instructor of Mathematics at the University of California, especially concerned with Lie theory and differential geometry.

At present he is devoting one-third time to assisting Professor S. Karlin of Stanford University in prepration of a book on "Total Positivity," a theory with applications to mechanics, differential equations, probability, and statistics.

Dr. Novikoff is a member of Sigma Xi, the American Mathematics Society, the Mathematics Association, the Canadian Mathematics Congress, the Sociétie Mathematique de France, the Society for Industrial and Applied Mathematics, and the Institute of Mathematical Statistics.

Singleton, Richard C. - Research Mathematical Statistician, Mathematical Sciences Department

Dr. Singleton received both B.S. and M.S. degrees in Electrical Engineering in 1950 from the Massachusetts Institute of Techology. In 1952 he received the M.B.A. degree from Stanford University Graduate School of Business. He holds also the degree of Ph.D. in Mathematical Statistics from Stanford University, conferred in 1960. His Ph.D. research was in the field of stochastic models of inventory processes, applying the general theory of Markov processes.

Dr. Singleton has been a member of the staff of Stanford Research Institute since January 1952. During this period, he has engaged in operations research studies, in the application of electronic computers to business data processing, and in general consulting in the area of mathematical statistics. His work the past several years has been mainly on the mathematical theory of self-organizing machines, magnetic-core switches, and error-correcting codes. He has written several articles for professional journals.

Before joining the Institute staff in 1952, Dr. Singleton's industrial experience included work in the product engineering and industrial engineering departments at Philco Corporation in Philadelphia, and employment as the chief engineer for a radio broadcasting station. He was an Instructor while doing graduate work at M.I.T.

Dr. Singleton is a member of a number of professional societies, including the Institute of Mathematical Statistics, the Institute of Electrical and Electronics Engineers, the Operations Research Society of America, the Research Society of America, Eta Kappa Nu, and Sigma Xi.

Crews, Robert W. - Senior Research Physicist,
Physical Electronics Laboratory

Dr. Crews received a B.S. degree in 1947, an M.A. degree in 1948, and a Ph.D. degree in 1952, all in Physics from Oregon State College. The title of his doctor's dissertation was "Charged Particle Observations of Li+T Reactions." While at Oregon State College he was a Teaching Assistant and Fellow. From 1949 to 1952 he was a Research Assistant at the Los Alamos Laboratory of the University of California.

Dr. Crews joined the staff of Stanford Research Institute in 1952 as a Research Physicist in the Theoretical Group of the Engineering Division. In 1954 he transferred to the Electron Devices Laboratory (now Physical Electronics Laboratory), where he has been engaged in experimental vacuum tube research. His fields of specialty include electron beams, accelerators, vacuum research, nuclear physics, and biophysics.

Dr. Crews is a member of Sigma Xi, the Scientific Research Society of America, the American Physical Society, and the American Association of Physics Teachers.

Macovski, Albert - Senior Research Engineer, Physical Electronics Laboratory

Mr. Macovski received a B.E.E. degree from City College of New York in 1950, and an M.E.E. degree from the Polytechnic Institute of Brooklyn in 1953.

In February of 1950 Mr. Macovski joined the staff of RCA Laboratories, Princeton, New Jersey, where he was engaged primarily in research involving television circuits, television displays, and communication systems. In the fall of 1957 Mr. Macovski joined the faculty of the Polytechnic Institute of Brooklyn as an Assistant Professor; he was promoted to the rank of Associate Professor in 1960. During this time, he was a consultant to the RCA Laboratories, working primarily on color television and communication systems. In July 1960, Mr. Macovski joined the staff of Stanford Research Institute, where he is working on displays, computer readout devices, facsimile techniques, video recording, and weather satellite television systems.

Patents have been issued in the fields of communications, electronic circuits, and television.

Mr. Macovski is a member of Tau Beta Pi and Eta Kappa Nu, and a Senior Member of the Institute of Electrical and Electronics Engineers.

Noon, Alonzo W. - Senior Mechanical Engineer,
Physical Electronics Laboratory

Mr. Noon received a B.S. degree in Mechanical Engineering from the University of Southern California in 1941. From 1941 to 1948, he was employed by the General Electric Company, where he was engaged in jet engine combustion research for five years and aircraft turbo-supercharger and voltage regulator development for approximately two years. Prior to joining the staff of Stanford Research Institute in December 1950, he was Assistant to the Manager of the Commercial Power Department of the San Diego Gas and Electric Company, and also did consulting in the field of industrial control.

At the Institute, Mr. Noon has worked with the Control Systems and the Physical Electronics Laboratories in the Engineering Sciences Division and with the Mechanics Department in the Physics Division. He has been concerned with research programs to develop and evaluate jet flame holders, with automatic document handling, and with wet-ink and electrostatic printing processes.

Thirteen patent assignments are in the field of combustion, industrial controls, automatic document handling, and printing systems.

Mr. Noon is a member of Tau Beta Pi, Sigma Xi, and the American Institute of Aeronautics and Astronautics.

COST BREAKDOWN

(First 18 months)

Personnel Costs		
Supervisory, 13 man-months at [redacted]/mo.	$[redacted]	
Staff Scientists, 17 man-months at [redacted]/mo.	[redacted]	
Senior Research Engineer and Physicists, 29 man-months at $[redacted]/mo.	[redacted]	
Research Engineer and Physicists, 62 man-months at $[redacted]/mo.	[redacted]	
Research Mathematicians, 12 man-months at $[redacted]/mo.	[redacted]	
Programmer, 34 man-months at [redacted]/mo.	[redacted]	
Editor, 2 man-months at [redacted]/mo.	[redacted]	
Technicians and Shop, 82 man-months at [redacted]/mo.	[redacted]	
Secretary, 12 man-months at [redacted]/mo.	[redacted]	
Total Direct Labor	[redacted]	
Payroll Burden at 16%*	[redacted]	
Total Labor plus Payroll Burden		[redacted]
Overhead at 95% of Salaries and Wages*		[redacted]
Total Personnel Costs		[redacted]
Direct Costs		
Lease of computers and associated equipment (see attached sheet)	$[redacted]	
Equipment purchases (see List)	[redacted]	
Machine time, B5000, 50 hours at [redacted]/hr.	[redacted]	
Travel and Subsistence, 10 Cross Country trips at [redacted]/trip; 29 days subsistence at [redacted]/day	[redacted]	
Shipping and Communications	[redacted]	
Report Costs	[redacted]	
Automobile expense, 10 trips, [redacted]/trip	[redacted]	
Total Direct Costs		[redacted]
Total Estimated Costs		[redacted]
Fixed Fee		[redacted]
Total Contract Cost		[redacted]

*The rates quoted are those currently approved for billing and estimating purposes. It is requested that contracts provide for provisional reimbursement on this basis subject to retroactive adjustment to fixed rates negotiated on the basis of historical cost data. Included in payroll burden are such costs as vacation and sick leave pay, social security taxes, and contributions to employee benefit plans.

Computers and Associated Equipment

(First 18-month Program)

1	Digital Computer, SDS 910, or equivalent, for on-line service, rental 6 months at [redacted]/mo.	$[redacted]
1	Digital Computer, CDC 3200, or equivalent, for on-line service, rental 6 months at [redacted]/mo.	[redacted]
	Computer time rental for simulation use, 50 hours of B5000 at [redacted]/hr.	[redacted]
	Disk or Drum memory for associative memory simulation, rental 6 months at [redacted]/mo.	[redacted]
	Total Computer and Associated Equipment Rental	[redacted]

Other Equipment

Parts for fabrication of 3 learning machines, estimated cost each--[redacted]	[redacted]
Parts for optical preprocessor for learning machine, including TV chain	[redacted]
Interface equipment, such as analog-digital converter, to match learning machine to the digital computers, estimated [redacted]/each set	[redacted]
Parts for building self-powered cart, fitted with sensors, communication link, electrical and mechanical control system	[redacted]
Total Other Equipment	[redacted]

Proposal for Research
Stanford Research Institute No. ESU 64-42

COST BREAKDOWN

(Second 18 months)

<u>Personnel Costs</u>		
Supervisory, 15 man-months at [redacted]/mo.	$ [redacted]	
Staff Scientists, 9 man-months at [redacted]/mo.	[redacted]	
Senior Research Engineer and Physicists, 42 man-months at [redacted]/mo.	[redacted]	
Research Engineer and Physicists, 72 man-months at [redacted]/mo.	[redacted]	
Research Mathematicians, 12 man-months at [redacted]/mo.	[redacted]	
Programmer, 37 man-months at [redacted]/mo.	[redacted]	
Editor, 2 man-months at [redacted]/mo.	[redacted]	
Technicians and Shop, 98 man-months at [redacted]/mo.	[redacted]	
Secretary, 12 man-months at [redacted]/mo.	[redacted]	
Total Direct Labor	[redacted]	
Payroll Burden at 16%*	[redacted]	
Total Labor Plus Payroll Burden		$ [redacted]
Overhead at 95% of Salaries and Wages*		[redacted]
Total Personnel Costs		$ [redacted]
<u>Direct Costs</u>		
Lease of Computers and Associated Equipment (see attached sheet)	[redacted]	
Equipment purchases	[redacted]	
Travel and Subsistence, 10 Cross Country trips at [redacted]/trip; 20 days subsistence at [redacted]/day	[redacted]	
Machine time, B5000, 50 hours at [redacted]/hr.	[redacted]	
Shipping and Communications	[redacted]	
Automobile expenses, 10 trips at [redacted]/trip	[redacted]	
Report Costs	[redacted]	
Total Direct Costs		[redacted]
Total Estimated Costs		[redacted]
Fixed Fee		[redacted]
Total Contract Cost		[redacted]

*The rates quoted are those currently approved for billing and estimating purposes. It is requested that contracts provide for provisional reimbursement on this basis subject to retroactive adjustment to fixed rates negotiated on the basis of historical cost data. Included in payroll burden are such costs as vacation and sick leave pay, social security taxes, and contributions to employee benefit plans.

Computers and Associated Equipment

3	Digital Computers, SDS 910, or equivalent for on-line service, total rental--54 months at [redacted]/mo.	[redacted]
1	Digital Computer CDC 3200, or equivalent for on-line service, total rental--18 months at [redacted]/mo.	[redacted]
	Disk or Drum rental for Associative Memory Simulation--18 Months at [redacted]/mo.	[redacted]
	Total	[redacted]

Equipment Purchases

Parts for equipment for setting up controlled environment for the demonstration, including display of all or part of the cart's activity	[redacted]
Total	[redacted]

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